OPERATING CHARACTERISTICS OF EXECUTIVE FUNCTIONING TESTS IN TRAUMATIC BRAIN INJURY

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The primary purposes of this study were to (1) determine if controls, mild, and moderate/severe traumatic brain injury (TBI) participants performed differently on a battery of executive functioning tests; (2) identify the operating characteristics of executive functioning tests in controls and traumatic brain injury participants; and (3) develop a linear combination of predictor variables that distinguished group membership. Participants consisted of 46 brain injured individuals and 24 non brain injured controls. All participants completed an extensive battery of executive functioning tests. Multiple one-way ANOVAs showed that, in general, no differences in test performance were noted between controls and mild TBI participants, but moderate/severe TBI participants consistently performed worse than either group. Results also showed that a computerized version of the Wisconsin Card Sorting Test yielded the highest positive predictive power among all tests, and the proportion of perseverative errors best distinguished groups in a discriminant function analysis. These findings provide information regarding the diagnostic accuracy of executive functioning tests in TBI and should assist clinical neuropsychologists in accurately identifying individuals with brain dysfunction.

INTRODUCTION

The Problem of Traumatic Brain Injury

Traumatic brain injury (TBI) is a physiological disruption of brain function that results from the head being struck, the head striking an object, or the brain undergoing an acceleration/deceleration movement (e.g., whiplash) without direct trauma to the head (American Congress of Rehabilitation Medicine [ACRM], 1993). There are approximately 1.5 - 2 million new cases of TBI in the United States each year (National Institute of Health, 1998), and prevalence estimates suggest that approximately 5.3 million Americans (2 percent of the population) live with TBI-related deficits today. Epidemiological evidence suggests that the annual incidence of TBI (200/100,000; Kraus, 1993) exceeds that of other serious neurological diseases such as multiple sclerosis (7.5/100,000; Mayr et al. 2003), Parkinson's disease (20/100,000; Fahn, 1995) and Alzheimer's disease (123/100,000; Schoenberg, Kokmen, & Okazaki, 1987) combined. Adolescents, young adults, and individuals over age 75 are at greater risk for sustaining TBI, and males are two times more likely to be injured than females. Forty-nine percent of TBI's are transportation related (e.g., involving motor vehicles, bicycles, pedestrians, and recreational vehicles), and 26 percent are due to falls. Firearms incidents account for 10 percent of all TBI's, and assaults account for 8 percent. The residual 7 percent are due to "other" causes (e.g., falling objects; Thurman, Alverson, Dunn, Guerrero, & Sniezek, 1999; Thurman, 2001). From an economic perspective, the direct costs of medical care

($4.5 billion), injury-related work loss and disability ($20.6 billion), and lost income resulting from premature death ($12.7 billion) contribute to an estimated annual cost of $38 billion dollars in the United States alone (Max, MacKenzie & Rice, 1991). After adjusting for inflation, theses costs are approximately $48.3 billion dollars annually (Lewin, 1992).

The symptoms following TBI are often devastating and involve *physical* (e.g., nausea, vomiting, dizziness, headache, blurred vision, sleep disturbance, quickness to fatigue, lethargy, or sensory loss), *cognitive* (e.g., involving attention, working memory, learning, speech/language, or executive functions), and *behavioral/emotional* (e.g., irritability, quickness to anger, disinhibition, or emotional lability; ACRM, 1993) systems.

Susceptibility of the Frontal Lobes in TBI

Relative to other areas of the cerebrum, the frontal lobes and polar areas of the temporal lobes are disproportionately susceptible to damage following TBI (Bigler, 1999). Their proximity to the frontal plate of the skull and the protuberances of the floor of the anterior cranial fossa (e.g., cribriform plate), and the medial temporal fossa, respectively, compounds their vulnerability to deceleration injuries with blunt head trauma (e.g., motor vehicle accidents, fall). This is evidenced by the high frequency of cases with acute cerebral contusions and hematomae in these regions following TBI (Benson & Miller, 1999; Stuss & Benson, 1986;). Follow-up neuroimaging studies attempting to elucidate the resolution of these lesions over time have found that chronic lesions eventually become hypodense, suggestive of encephalomalacia and subsequent functional loss (Benson & Miller, 1999). When this type of pathology involves the frontal lobes, functional deficits in *behavior and emotion* (e.g., impulsivity, facetiousness, apathy and behavioral regulation;

Benson & Miller, 1999; Blumer & Benson, 1975; Damasio & Anderson, 1993; Lhermitte, Pillon, & Serdaru, 1985; Malloy, Bihrle, Duffy, & Cimino, 1993; Sarazin et al., 1998) and *cognition* (e.g., sequencing, abstract thinking, planning, inhibition, and working memory; Anderson, Bigler, & Butler, 1995; Brown & Levin, 2001; Kimberg, D'Esposito, & Farah, 1999; Lezak, 1995;) may follow. Behavior, emotion, and cognition collectively contribute to executive functioning which, according to Lezak (1995), is "the capacity that enables a person to engage successfully in independent, purposive, self-serving behavior" (p. 42). Deficits in executive functioning (executive dysfunction) have been referred to as the "dysexecutive" (Wilson, Evans, Emslie, Alderman, & Burgess, 1998) or "frontal lobe" syndrome (Malloy et al., 1993), but some researchers (Bigler, 1988; Stuss & Alexander, 2000) have cautioned against the notion of describing a syndrome based on its anatomical locus.

Although the frontal lobes and temporal poles are most susceptible to damage following TBI (Bigler, 1999), the effect of rapid inertial changes to the head or body sometimes results in diffuse pathology throughout the cerebrum. In injuries that include blunt head trauma, the site of impact to the skull (e.g., the frontal plate when striking the windshield in an MVA) represents the "coup" site and is the location where brain damage is usually maximal. The site directly opposite from the coup location (e.g., the occipital pole) is the "contra-coup" site. Significant pathology may occur at the contra-coup site due to the brain retracting and striking the occiput following the initial rapid deceleration of the skull. Massive negative pressure gradients resulting from the initial impact also contribute to damage at the contra-coup site. Contusions, sub- and epi-dural hematomae, intracerebral hemorrhages and primary axotomy are all examples of the primary injury in

TBI. Secondary injury includes intracellular cytotoxicity, herniation, ischemia and secondary axotomy that may differentially affect outcome.

Because of the diffuse and heterogeneous nature of the primary injury and the unique secondary injuries that are unique in each case, TBI patients have not generally been considered ideal candidates for discrete structure/function studies (Damasio & Damasio, 1999; Damasio & Geschwind, 1985; Damasio & Damasio, 1989). However, their proclivity for sustaining prefrontal pathology suggests that they may be good candidates for studying dysexecutive behavior.

Models of Executive Functioning.

Attempts to elucidate the nature of executive functioning have been made by neuropsychologists, physiological psychologists and most recently cognitive psychologists. Early explanations based on neuropsychological understanding of prefrontal/frontal lobe functioning were espoused by Luria (1973). According to Luria, the brain is organized hierarchically into three functional units. The first functional unit provides "regulating tone and waking and mental states" (p. 44) and involves the ascending and descending reticular activating systems. The second functional unit is involved in receiving, analyzing and storing information and involves primary, secondary, and tertiary cortical zones. Medial-temporal lobe structures are also part of this unit. The final functional unit, which sits atop the neuraxis in the position of the frontal lobes, programs, regulates, and verifies activity and involves the frontal lobes. This unit performs executive functioning and is highly reliant upon the integrity of the prefrontal cortices for performance. Although Luria provided an integrated neuropsychological explanation of executive behavior, other researchers provided more specific hypotheses about the hierarchical nature of cognitive functioning.

Following Shiffrin and Schneider's (1977) seminal paper on automatic and controlled processes, Shallice and Evans (1978) and Shallice (1982) proposed a hierarchical model of behavior that included executive/control processes. Shallice's information processing model was comprised of cognitive units, schemas, contention scheduling, and a supervisory attentional system (SAS). Shallice referred to cognitive units as modules of cognitive processes (e.g., memory, language) that were generally represented by specific anatomical pathways (e.g., medial temporal lobe, perisylvian region). Schemas refer to behaviors that are dependent upon multiple cognitive units; however, schemas that are routinized and overlearned exist for activities that place a minimal load on conscious behavior such as throwing a spiral football pass for an experienced quarterback or riding a bicycle for an expert cyclist. These complex yet routinized behaviors place a minimal load on an organism's attentional capacity. Contention scheduling refers to the selection of a specific set of schemas in order to meet the organism's demands within the environmental milieu. For example, contention scheduling is required when one negotiates a familiar library's organizational system in order to check out a book. Finally, the SAS organizes and manages all responses while negotiating nonroutine tasks. The SAS is especially activated when contention scheduling does not work or when the solution to an environmental contingency is unknown. Shallice posited that the frontal lobes perform the functions of the SAS and that contention scheduling, but not the SAS, is often preserved following brain injury. In this example, the functions of the SAS appear synonymous with executive control.

Baddeley (1986) suggested that executive processes play an integral role in working memory. He suggested a Multiple Component Model of working memory that included two highly specific slave systems responsible for the processing and temporary maintenance of verbal (e.g., Articulatory Loop) and visuospatial (e.g., Visuospatial Scratch Pad) material, and a third component referred to as the Central Executive. The function of the Central Executive is to control and regulate the working memory system and is thought to include the prefrontal cortex.

Models of frontal lobe functioning from animal lesion and unit recording studies have also contributed to our understanding of some of the frontal lobe functions. Fuster (2002) reported that the prefrontal cortex integrates temporally separate units of perception, action and cognition into a sequence toward a goal. He suggested that temporal organization (e.g., if this now, then that later; if earlier that, then now this) occurred by: (a) invoking a preparatory set; (b) utilizing working memory; and (c) facilitating inhibitory control of interference, and that temporal organization was mediated by the prefrontal cortex and was executive in nature.

Goldman-Rakic (1987) also emphasized the role of the prefrontal cortex in maintaining internal representations across time. In work with non-human primates, she showed a strong relationship between activity in specific neurons in the prefrontal cortex and performance on delayed-response tasks. She hypothesized that internal representations guided behavior and that the maintenance of these representations was performed by a cortical network that included the prefrontal cortex. Researchers in the area of clinical-cognitive neuroscience have corroborating evidence from functional magnetic resonance imaging (fMRI) for the role of focal prefrontal activation in working memory tasks (Braver et al., 1997; Cohen et al., 1997; Curtis & D'Esposito, 2003; D'Esposito, Postle, & Rypma, 2000)

Cognitive psychologists have emphasized how impaired working memory impacts cognition (Cohen & Servan-Schreiber, 1992). The authors suggested that information-processing deficits in patients with prefrontal damage may be caused by "a degradation in the ability to construct and maintain an internal representation of context" (p. 46). Context refers to information held in mind in order to mediate an appropriate behavioral response. This theory was based on previous work by Fuster (1980) and Goldman-Rakic (1987) who hypothesized that specific cells in the prefrontal cortex are specific to a particular stimulus and response and remain active during the delay between these. Cohen and Servan-Schreiber (1992) suggested that the prefrontal cortex was directly involved in maintaining representations that inhibit reflexive or habitually reinforced behaviors to obtain a goal (e.g., response inhibition). This function of the prefrontal cortex, to maintain internal representations that guide behavior, was later referred to as *cognitive control* (Braver, Barch, & Cohen, 1999; Miller & Cohen, 2001;).

According to Miller & Cohen (2001), the prefrontal cortex exerts cognitive control by biasing signals, in a top-down fashion, in those parts of the brain responsible for processing sensory (e.g., secondary and tertiary regions of occipital, temporal, and parietal cortices), limbic and memory retrieval (e.g., direct and indirect connections with the amygdala, hypothalamus, and hippocampus), and motor (e.g., supplementary motor area, pre-supplementary motor area, premotor area, cerebellum, superior colliculus, and basal ganglia) functioning. The authors state, "The aggregate effect of these bias signals is to guide the flow of neural activity along pathways that establish the proper mappings between inputs, internal states, and outputs needed to perform a given task" (p. 171).

The *context maintenance hypothesis* proposes that behavioral inhibition may reflect the operation of PFC-mediated context maintenance processes, and that working memory and response inhibition reflect the operation of a single underlying processing mechanism. In this context, inhibition refers to the ability to inhibit or overcome highly learned or otherwise pre-potent but contextually inappropriate response tendencies. As previously noted, the linking of PFC representations to the organization of prospective action has been proposed to be a critical function of the prefrontal cortex (Fuster, 1997; Goldman-Rakic, 1987), and preparation to overcome contextually inappropriate responses is an important component of this system.

The aforementioned models of executive functioning/control have provided a theoretical framework for the development of psychological tests that measure some of the individual component processes of executive functioning/control (e.g., updating, context maintenance, inhibition). Such tests have been developed from the information-processing and chronometric perspectives in cognitive psychology and provide computerized assessment of specific processes and yield accuracy and reaction-time data that can be analyzed in light of predictions derived from cognitive models of executive function. Given this, computerized psychological tests which have been developed from the cognitive psychological framework may be better able to parse the component processes associated with executive functioning/control and subsequently provide a more accurate picture of the specific executive deficit that occurs after TBI. Compared to traditional neuropsychological tests of executive dysfunction, computerized psychological tests developed from the cognitive psychological framework may improve diagnostic accuracy and aid the clinician in better characterizing the exact nature of executive functioning/control problems that may occur after mild TBI (Brooks, Fos, Greve, & Hammond, 1999).

Cognitive psychological tests have not been widely used in clinical settings; but they have been used to study executive functioning/control and working memory in a wide range of diseases and disorders. For example, the N-Back task (see Methods section below), a prototypical working memory paradigm that taps all of the primary components typically considered to be subsumed by working memory: maintenance and manipulation, with manipulation comprising sequencing, updating and temporal tagging, has been used in studies of individuals with schizophrenia (Jansma, Ramsey, Van Der Wee, & Kahn, 2004; Perlstein, Dixit, Carter, Noll, & Cohen, 2003), pediatric TBI (Levin et al., 2004), multiple sclerosis (Lengenfelder, Chiaravalloti, Ricker, & DeLuca, 2003; Wishart et al., 2004), obsessive compulsive disorder (Van Der Wee et al., 2003), Klinefelter syndrome (Fales et al., 2003), and HIV (Hinkin et al., 2002). Another cognitive psychological test, the AX version of the original Continuous Performance Test (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956; AX-CPT), taps sustained attention, inhibitory control, and the active maintenance component of working memory, and has been used in studies of neurologically intact individuals, older adults, and in individuals with schizophrenia (Braver, Cohen, & Barch, 2002). The cued Stroop task, a computerized single-trial, cued version of the original Stroop test (Cohen, Barch, Carter, & Servan-Schreiber, 1999), taps the ability to form and actively maintain context representations and to implement cognitive control more explicitly than does the card version of the Stroop test and has been used in studies of neurologically intact individuals, and individuals with schizophrenia, depression (Cohen, Barch, Carter, & Servan-Schreiber, 1999), and TBI (Seignourel et al., 2004). The computerized Wisconsin Card Sorting Test (WCST; Kimberg, D'Esposito, & Farah, 1997) is a modified version of the traditional WCST that neuropsychologists have been using in clinical settings. The modified version purportedly places a greater demand on cognitive set shifting and speed of information processing and has been used in neurologically intact individuals taking bromocriptine - a dopamine receptor agonist (Kimberg, D'Esposito, & Farah, 1997).

Although the aforementioned cognitive psychological tests offer some advantages over traditional tests of executive functioning/control, they have only relatively recently been developed and are not yet in wide clinical use. The tests have also yet to demonstrate adequate reliability and validity, and have not been compared to traditional neuropsychological tests with regard to their diagnostic accuracy. What is needed is a study that combines the use of cognitive psychological tests with traditional neuropsychological tests to determine which tests are most useful in identifying individuals with executive dysfunction/dyscontrol.

Reliability and Validity of Traditional Executive Functioning Tests.

Evaluating the cognitive and emotional sequelae following central nervous system damage constitutes the hallmark function of the clinical neuropsychologist (Eubanks, 1997). These assessments involve collecting data by medical records review, conducting clinical interviews (with patient and corroborating others), making behavioral observations during the evaluation, and performing formal neuropsychological testing (Lezak, 1995;

Vanderploeg, 2000). This process is complete when the clinician integrates these data and communicates the findings to the referral source (Meyer et al., 2001).

Assessing neuropsychological performance through the use of objective standardized tests is critical to making accurate diagnostic, prognostic and treatment-related decisions. A fundamental prerequisite for using neuropsychological tests to identify neurocognitive and/or neurobehavioral dysfunction is that the instruments have adequate reliability and validity (Anastasi, 1988). In the domain of psychometric testing, *reliability* refers to the degree of consistency in obtained performance scores across test administrations. Although no psychometric test has absolute reliability, there should be adequate consistency in performance across conditions to ensure that the observed change in test performance represents change in the construct(s) the test purportedly measures as opposed to error variance. *Validity* refers to the degree to which a test fulfills the purposes for which it was intended and includes content, criterion-related, and construct validity (Retzlaff & Gibertini, 2000). For example, if the "Demery Test of Marine Preparedness" is to be valid, it should (1) test level of physical fitness, firearms proficiency, and knowledge of battle-field tactics (content validity); (2) predict performance on an objective criterion such as war-fighting skill (criterion-related validity); and (3) measure the degree to which the test measures a theoretical construct such as "combat effectiveness" (construct validity). If tests are not reliable and valid, they may yield inaccurate information and thwart diagnostic accuracy.

Traditional tests of executive functioning generally suffer from low reliability and validity (Bowden et al., 1998; Cripe, 1996; Kafer & Hunter, 1997; Miyake, Emerson, & Friedman, 2000; Rabbitt, 1997). Bowden et al. (1998) tested the alternate form reliability of the Wisconsin Card Sorting Test (WCST) in a sample of 75 neurologically normal college students. In the first form, the order of sorting was performed as explained in the test manual (e.g., color, then form, then number). In the alternate form, the sorting order was changed (e.g., form, then color, then number). The authors reported alternate-form reliability coefficients that ranged from .28 for the number of "correct" responses, to .60 for the number of "categories" achieved. The average reliability coefficient across all six scores was .43. Using Cohen's (1988) assertion that correlation coefficients of approximately .20, .50 and .80 are small, medium and large, respectively, the results from this study indicate that the alternate forms reliability of the WCST is marginal at best. In fact, the authors caution, "Since clinicians employing a test with low reliability are likely to be frequently misled by erroneous information, we recommend that clinicians should not employ the Wisconsin until such times as the test is shown to be of adequate reliability, or is improved to meet acceptable standards" (p. 253). While the authors are correct in recommending that test results from the Wisconsin Card Sort be used cautiously due to low reliability, the authors may have gone beyond the data by cautioning against the use of the test under any circumstances.

In the WCST manual (Heaton, Chelune, Talley, Kay, & Curtiss, 1993), the authors reported one paper that addressed the reliability of the test. Axelrod, Goldman, and Woodard (1992) conducted two experiments that assessed the intrascorer/intrarater reliability of the WCST. In the first experiment, they reported interscorer/intrascorer reliability coefficients, for three experienced clinicians, which ranged from .88 for nonperseverative errors to .93 for perseverative responses. In a second experiment using novice scorers, they reported good to excellent interscorer and intrascorer agreement as evidenced by reliability coefficients from .75 to .97. Although these reliability coefficients for scoring the WCST are excellent, no evidence is reported in the test manual regarding the stability of performance across repeated test conditions (e.g., test-retest reliability).

Miyake, Emerson, and Friedman (2000) suggest that the primary reason why executive functioning tests have insufficient reliability is due to a lack of novelty associated with many of these tests at re-test. Phillips (1997) stated that it is imperative for any test of frontal lobe functioning to be novel and effortful. The need for novelty is based on the idea that when a series of novel test problems are negotiated for the first time, effortful and controlled processing (e.g., hypothesis testing, problem solving, monitoring and updating) must be applied to find a solution to the problem. Once the solution has been identified, novelty is lost and automatic processing takes over and the task no longer becomes a test of executive abilities. Assuming that novelty is critical to the assessment of executive functioning, what is needed is a test that is novel and effortful across test administrations.

Most tests of executive functioning suffer from poor construct validity. Given the numerous problems defining the executive functions, research in the area of the construct validity of executive functioning has been justifiably slow (Miyake et al., 2000). For example, the WCST has been purported to assess executive functioning; however, without an adequate definition, it is difficult to understand how the test can measure it. The test is said to specifically measure mental set shifting, cognitive flexibility, problem solving and organizational abilities. The degree of overlap between these constructs is unknown and without adequate study, the examiner is left to decide what the test measures. These issues illustrate some of the psychometric dilemmas that clinicians face when assessing executive functioning.

Issues Related to Diagnostic Accuracy of Executive Functioning Tests.

Adequate reliability and validity of psychometric tests are central concepts in neuropsychological assessment. Once these properties have been demonstrated in a given test, a test's ability to detect brain damage and any specific features of the damage (e.g., location) is examined. These functions have been referred to as a test's sensitivity and specificity, respectively. *Sensitivity* refers to how well a test detects a disorder if the person actually has the disorder, and *specificity* refers to the likelihood that the test will be normal if the person does not have the disorder (Retzlaff & Gibertini, 2000). Adequate sensitivity and specificity help the clinician identify "true positives" and "true negatives" among a population of unknowns. This approach to identifying the presence/absence of a disorder, sometimes referred to as a test's "hit-rate," is derived from signal detection theory. In psychometric testing, however, indices that reflect a test's capability to accurately perform these discriminating functions are referred to as the test's "operating characteristics" (Retzlaff & Gibertini, 2000). Operating characteristics include positive and negative predictive power. *Positive predictive power* (PPP) is the ratio of true positive cases to all test positives. More specifically, it refers to the probability that an impaired test score represents a person with the disorder. *Negative predictive power* (NPP) refers to the ratio of true negatives to all test negatives, and represents the probability that a person without an impaired test score does not have the disorder (Elwood, 1993). The reciprocal of PPP is the true positive rate, and the reciprocal of NPP is the false negative rate. These indices allow us to derive probability estimates about the likelihood that a positive test finding represents a disorder.

Traditional neuropsychological tests of executive functioning are marginally capable of differentiating between brain-damaged and non brain-damaged controls; however, these tests have not consistently shown adequate specificity to frontal lobe damage per se (Anderson, Damasio, Jones, & Tranel, 1991; Anderson et al., 1995; Axelrod et al., 1996; Costa, 1988; Heaton et al., 1993). Given that most executive functioning tests have adequate sensitivity but poor specificity and low positive and negative predictive power, these tests may ultimately fail to accurately discriminate between those individuals who have brain damage and those who do not. Developing tests with adequate sensitivity, specificity, positive and negative predictive power for assessing executive functioning is an area that needs further empirical investigation.

Purposes of the Study

The purposes of this study were threefold: (1) we wanted to determine how different groups of participants (e.g., controls, mild TBI, and moderate/severe TBI) performed on tests of executive functioning; (2) we wanted to identify and compare the operating characteristics of different executive control tests in the diagnosis of TBI and determine if level of positive predictive power differed across different types of tests; and (3) we wanted to develop a linear combination of predictor variables that could predict group membership. Our specific aims, and hypotheses/predictions for this study were as follows:

Aim I: Our first aim was to compare performance, on a broad range of tests designed to assess executive functioning, between participants who have sustained a documented TBI (mild or moderate/severe) and healthy comparison participants who have not sustained a TBI.

Hypothesis/prediction I: We hypothesize that group mean performance scores, on all *individual* tests designed to measure executive dysfunction, will differ as a function of group membership (e.g., control, mild, moderate/severe). We predicted that controls would perform best and mild TBI participants would perform better than moderate/severe TBI participants.

Aim II: Given the construct specificity problems of traditional neuropsychological tests, our second aim was to determine if "purer" tests (e.g., cognitive psychological tests) of executive dysfunction would yield greater power in predicting the presence of brain dysfunction when compared to traditional neuropsychological tests or tests designed to assess everyday executive dysfunction. Our goal was to define the operating characteristics of each test at three levels of impairment and then, through simple visual analysis, determine if positive predictive power (PPP) differed as a function of test type (e.g., cognitive, neuropsychological, test of everyday executive dysfunction).

Hypothesis/prediction II: We hypothesized that cognitive psychological tests would yield higher PPP because they are thought to be “purer” measures of executive dysfunction than other tests. Specifically, we predicted that cognitive psychological tests of executive dysfunction would yield greater positive predictive power than traditional neuropsychological tests or tests of everyday executive dysfunction (e.g., Behavioral Assessment of the Dysexecutive Syndrome subtests).

Aim III: Our third aim was to determine if predictor variables from neuropsychological tests were able to reliably discriminate group membership (e.g., control, mild, or moderate/severe).

Hypothesis/prediction III: We hypothesized that a weighted linear combination of predictor variables would be useful in differentiating between groups. For reasons described in Aim II above, we predicted that the best weighted linear combination of predictor variables that could discriminate group membership would include a greater number of cognitive psychological tests than traditional neuropsychological tests or tests of everyday executive dysfunction.

METHODS

Participants

The sample consisted of 46 participants with a history of TBI and 24 non-TBI controls (N=70). All participants were respondents from flyers posted at the University of Florida Health Science Center or from an advertisement that appeared in the Brain Injury Association of Florida newsletter. All respondents underwent a brief telephone screening to ensure that they met the basic inclusion criteria as either a TBI or control participant. Potential participants were excluded from the study if they had previously been diagnosed with serious psychopathology (e.g., schizophrenia, bipolar disorder), attention deficit disorder, learning disability, or reported a history of chronic alcohol or drug abuse. Prior to actively participating in the study, respondents were asked to bring medical records with them to the study if they had access to them. All participants provided written informed consent according to procedures established by the Health Science Center Institutional Review Board at the University of Florida. All individuals were paid $50.00 for their participation.

TBI individuals were classified as having sustained a TBI as defined by the American Congress of Rehabilitation Medicine (ACRM, 1993). Specifically, any mechanically induced disruption of brain function, as evidenced by (a) any period of loss of consciousness; (b) any retrograde or anterograde amnesia; (c) any alteration in mental status immediately following the injury (e.g., feeling dazed, disoriented or confused); or focal neurological sign(s) constituted a positive history of brain injury. Brain injury severity (e.g., mild, moderate, severe) was determined by reviewing medical records information regarding neurological status at the time of injury such as: presence/absence and duration of loss of consciousness (LOC), Glasgow Coma Scale (GCS) score, neuroradiological reports, and other pertinent information (e.g., neurological examination, neuropsychological reports).

Seven TBI participants (1 mild, 1 moderate, and 5 severe TBI) brought medical records with them to the study. Four mild TBI participants did not go to the emergency room after their injuries. One of those 4 was assessed by an athletic trainer and another participant sought outpatient treatment from their primary care physician for post-traumatic headache. For the remaining participants who were admitted to the emergency room after their injury and who did not bring medical records to the study (n=35), brain injury severity was determined retrospectively from data collected by a semi-structured interview (see Appendix) that was completed with the participant and, if present, a collateral informant. For the thirty-five participants who did not bring medical records to the study, information regarding the presence/absence and duration of LOC and/or PTA that was obtained through interview was used for injury severity classification. The reliability and validity of retrospective assessment of brain injury severity based on this approach has been demonstrated by past research (King, Crawford, Wenden, Moss, Wade, & Caldwell, 1997; McMillian, Jongen & Greenwood, 1996), and the method of retrospective questioning used in this study was based on the methods described by King et al. (1997). Patients were asked to recall as much as they could remember, in chronological order, about what happened immediately before and after their injury. They were reminded to state *only what they personally could remember* and *not what they had come to learn from others since the accident.* The interviewer required lucid recall of material, excluding any "islands of memory" (Russell, 1971) until such time that the participant was able to describe a continuous stream of memories. Although the method of retrospective interviewing to determine brain injury severity was used in the present study, there are limitations to this approach. There is an assumption that the information the patient tells the examiner about their injury (e.g., what happened, who was there, where the event occurred, what the last memory was before accident, what the first memory was after accident, etc.) is free from factual material they learned from others (e.g., family, friends, medical personnel). Another limitation is that the duration of coma is added to the duration of PTA as an index of brain injury severity. Patients are at times intentionally put into a coma, via pharmacological agents, to prophylactically manage intracranial swelling. If this is the case, the duration of PTA, and subsequently brain injury severity, may be artificially inflated in some cases. Given these limitations, external validation of injury severity classification should be sought when relying on retrospective interview alone.

In order to determine if retrospective interviewing alone was a valid method for determining injury severity, we compared injury severity classification (e.g., mild, moderate, or severe) obtained through retrospective interviewing to injury severity classification obtained through medical records review for the seven TBI participants who brought their medical records to the study. Given the post-hoc nature of this analysis, the researcher who performed the comparison was not blinded to injury severity at the time of the medical records review. Subsequent comparison showed 6/7 participants had been correctly classified. One case that had previously been classified a severe TBI became an unconfirmed severe after it was found that positive neuroradiological findings were the only medical records available for this participant. Based on the previous work of King et al. (1997) and the present findings, we concluded that our method of retrospective interviewing was a valid method of determining brain injury severity.

Once all injury-related information was obtained, TBI participants were classified as having sustained either a mild, moderate or severe TBI. *Mild TBI* was operationalized as an initial GCS score of 13 - 15 (Teasdale & Jennett, 1974), duration of LOC less than 30 minutes, or a duration of PTA less than 24 hours (ACRM, 1993); *moderate TBI* was a GCS score of 9 - 12, duration of LOC from 31 minutes - 6 hours, or duration of PTA of 1 - 7 days (Lezak, 1995); and *severe TBI* was a GCS score of less than 9, duration of LOC greater than 6 hours, or duration of PTA greater than 7 days. Finally, each participant was assigned to either a control (n=24), mild TBI (n=20), or moderate/severe TBI (n=26) group.

Procedure

All testing was completed at the Evelyn F. and William L. McKnight Brain Institute of the University of Florida. Following the aforementioned informed consent procedure, all participants underwent a 45-minute semi-structured clinical interview to collect relevant demographic data and, in the case of the TBI group, information related to the nature of their injury. All participants, and informants if present, completed "self" and "informant" versions of the modified Neurobehavioral Rating Scale – Revised (NRS-R; Mathias & Coats, 1999) and Dysexecutive Questionnaire (DEX; Wilson et al., 1998). For participants who arrived alone for the study, blank "informant" rating forms and a preaddressed stamped envelope were provided and the participant was asked to have someone who could document their everyday functioning complete and mail back the forms to the study coordinator. Frequency count indicated that 59/70 (84%) informant reports for the DEX and modified version of the NRS-R were obtained.

After all forms had been completed, participants underwent a 4-5 hour testing session. To ensure that optimal performance was maintained throughout testing, participants were observed for signs of excessive fatigue (e.g., falling asleep, carelessness, boredom) and were afforded a brief rest period of 5-minutes, if necessary.

Tests were completed in a quasi-randomized fashion. All "computerized" tests (e.g., N-Back, AX-CPT, AX-CPT Interference, Cued Stroop) except the WCST (Computer) were randomized and performed in one testing "block." All other tests (e.g., paper-pencil) were randomized and completed in a different testing "block." The only computerized test that was completed during the paper-pencil block was the WCST (Computer). Given the variation in administration instructions in the WCST (Computer), the WCST (Card) immediately preceded the WCST (Computer) for all participants. Type of tests administered first (e.g., computer, paper-pencil) was counterbalanced between participants to control for order effects.

Measures/Apparatus

Most tests are touted as measures of executive control (Table 1). Other tests (e.g., PASAT, Digit Symbol) were administered for comparison against the current battery of executive control tests because these tests are highly sensitive to brain damage (Cicerone & Azulay, 2002; Gronwall & Wrightson, 1981;). Raw scores from all tests were converted to standardized scores (Z-scores) based on means and standard deviations obtained by the non-TBI control group in this sample.

Computer-based cognitive psychological tests

N-Back. The N-Back task is a sequential letter memory task that parametrically varies working memory load across 0-, 1-, 2- and 3-back conditions. In the 0-back condition, the subject makes a button press in response to a letter (target) that matches a pre-specified letter (e.g., "X"). In the 1-back condition, the target becomes any letter that was identical to the one immediately preceding it. In the 2- and 3-back conditions, the target becomes any letter identical to the one presented two and three trials back, respectively. Stimulus encoding and response demands are constant across conditions. Only requirements to maintain and update increasingly greater amounts of information at higher loads differ. This task may be considered a prototypical working memory paradigm in that it taps all of the primary components typically considered to be subsumed by working memory: maintenance and manipulation, with manipulation comprising sequencing, updating and temporal tagging (Perlstein et al., in press). The dependent variables for this task are the proportion of errors (e.g., total errors/total trials) on trials 1 and 2 (Nback Low) and trials 3 and 4 (Nback High).

Stroop (computer). This is a modification of Golden's Stroop task (Golden, 1978) where stimuli vary in two dimensions (e.g., color words displayed in color) and participants are instructed to respond to one of the two dimensions (read the word, or name the color). The context provided by the task instruction (e.g., name the color) must be used to override the influence of the stronger dimension (e.g., read the word) when the task is to respond to the less prepotent or automatic dimension (e.g., name the color).

Table 1

Hypothesized executive control constructs measured by each dependent measure

TEST	*RESPONSE INHIBITION*	*WORKING MEMORY/ ACTIVE MAINTENANCE*	*SET SHIFTING*	*PLANNING & ORGANIZATION*	*PROBLEM SOLVING*
N-Back		X			
Stroop (Computer)	X	X	X		
AX-CPT	X	X			
AX-CPT Interference	X	X			
WCST	X	X	X	X	X
Stroop (Card)	X				
Trail Making Test "B"		X	X		
Digit Span Test		X			
PASAT		X			
Digit Symbol Test		X			
Rule Shift Cards	X	X	X		
Action Program Test				X	X
Key Search Test				X	X
Zoo Map Test		X		X	X
Modified Six Elements	X	X	X	X	

Note. CPT=Continuous performance test; WCST=Wisconsin Card Sorting Test; TOL=Tower of London; PASAT=Paced Auditory Serial Addition Test.

Context provided by the task instructions must be used to overcome this influence of the stronger dimension when the task is to respond to the weaker one (Cohen, Dunbar, & McClelland, 1990). However, traditional Stroop experiments do not usually place strong demands on the ability to hold information in mind in order to mediate an appropriate behavioral response (context maintenance; Perlstein, Carter, Barch & Baird, 1998). This is because trials are almost always blocked by task (i.e., word reading or color naming), so that the same instructions (context) are repeatedly reinforced. However, reliance on context could be increased by (a) varying the task to be performed on each trial and (b) introducing a delay between the task instructions for each trial and the stimulus to be responded to. We predicted that such manipulations should further increase the sensitivity of this task to deficits among patients with traumatic brain injury.

At the beginning of each trial, participants heard an instructional cue (the word "color" or "word" presented auditorily by computer) followed by a stimulus presented on the monitor. Participants were instructed to respond verbally to the stimulus, as designated by the cue, as quickly and accurately as possible. Each stimulus remained on the screen until the participant responded. Reaction times (RTs) were automatically recorded by a voice-activated relay connected to the computer, and the examiner manually coded response accuracy. Although rare, on the occasion that the voice-activated relay picked-up irrelevant words or noises and then automatically proceeded to the next trial, the examiner noted the trial number and flagged the trial as invalid. Invalid trials were excluded from later statistical analyses. Two interstimulus intervals between the cue and the onset of the stimulus were used: 1-second and 5-seconds. Three colors and color words were used (red, green, and blue), presented in each of three conditions (congruent, neutral, incongruent). Congruent stimuli consisted of one of the three color names presented in its own color. Incongruent stimuli consisted of a color name presented in one of the two remaining colors. Neutral stimuli were four colored XXXXs for color naming trials and color words displayed in black for word reading trials. A total of 180 experimental trials were distributed equally across tasks (color naming, word reading), cue stimulus ISI (short, long), and conditions (congruent, neutral, incongruent) and, within conditions, across the different stimuli for that condition. Trials were pseudo randomly ordered for each participant with the constraint that each trial type occurred twice in every 24 trials. The dependent variable for this task is the proportion of errors during the color incongruent trials for long (CL Incongruent) and short (CS Incongruent) ISI trials.

AX-Continuous Performance Test (CPT). In this version of the CPT, randomly chosen letters are presented sequentially in a visual display and participants are instructed to respond to the letter "X" only when it follows an "A." Performance on this task relies on the representation and maintenance of context information, insofar as the correct response to "X" depends on the previous stimuli (A or non-A). We used a version of this task that we modified in two ways (Servan-Schreiber, Cohen, & Steingard, 1997). First, we increased the frequency of target (A-X) sequences to 70% of trials, with the remaining 30% divided evenly between three distracter conditions: a non-A followed by an X (which we referred to as the BX condition); an A followed by a non-X (AY); and a non-A followed by a non-X (BY). We hypothesized that this frequency distribution would induce a strong tendency to respond to X, since that is the correct response for 87.5% of the trials in which X appeared. This tendency would have to be inhibited in the BX condition, relying on the use of context (non-A stimulus) to overcome the tendency to respond to X. Thus, in our variant of the task, a failure to process context can be indexed not only by misses in the AX (target) condition, but also by false alarms in the BX condition. Our second manipulation was to vary the delay (1-second or 5-seconds) between the cue (A/non-A) and the probe (X/non-X) stimuli in order to determine if errors increased under longer delay conditions. The 5-second delay is believed to be more difficult because it places a greater demand on the ability to actively maintain context information across time. Participants responded by pressing a button on a box connected to a computer, which recorded the response and reaction time (RT). Stimuli appeared for 250 ms, and participants had a total of 1-second from onset in which to respond, irrespective of interstimulus interval (ISI). Distracter stimuli (non-A and non-X) consisted of the remaining letters of the alphabet, with the exception of K, which was excluded because of its similarity to X. Feedback was provided in the form of a beep for correct responses, a buzzer sound for false alarms or misses and no sound for a correct rejection. A total of 400 trials were run. ISI and condition were varied pseudorandomly over trials, with the constraints that 50% of trials occurred at each ISI, the distribution of conditions was the same for each ISI , and each trial type occurred at least once every 20 trials. The dependent variable used for this task is d' context (d' AX No Interference Long Delay=d' AX NoInt Long) which is calculated using AX (target) and BX (non-target) trials to provide an overall measure of use of cue information to disambiguate probe stimulus states.

AX-CPT Interference. The format of this task is identical to the AX-CPT with the exception that 2 random letters are presented during the delay between the cue (A-non-A) and the probe (X/non-X). The purpose of this procedure was to determine if the presence of the interfering letters degraded context maintenance. Consistent with the AX-CPT, the dependent variable used for this task is d' context (d' AX Interference Long Delay=AX Int Long).

Wisconsin Card Sorting Test (WCST-Computer). This task is a computerized, speeded version of the WCST developed by Kimberg, D'Esposito, and Farah (1997a). The task requires participants to match a series of target cards presented individually in the middle of the screen with any one of four reference cards shown near the top of the screen. Participants were instructed to sort the target cards into piles under the reference cards according to one of three categories or stimulus attributes-color, number, or shape. Participants were also told that only one attribute was correct for each target card. Each target card appeared until a response was given or a maximum of five seconds had elapsed, at which point the next trial commenced immediately. Participants receive visual feedback, (e.g., "right" or "wrong") appearing below the sorted target card, based on the accuracy of their response. If the participant does not categorize the target card within the 5-second time constraint, the phrase "time out" appears to the right of the target card in the ensuing trial. The category stays the same until the participant correctly performs eight consecutive sorts, at which time the sorting criterion changes. The participants are initially told that the sorting criterion changes, but they are not explicitly told the exact number of correctly sorted cards to be achieved before the criterion shifts. After practicing on 18 cards, the main task begins and continues until the participant successfully achieves 15 sorting categories or the total number of target cards exceeds 288. The method of modified instructional cues at the beginning of the task has proven useful in distinguishing concept formation versus perseverative responding deficits in other patient populations with executive dysfunction (e.g., schizophrenia; Goldman, Axelrod, & Tompkins, 1992). The dependent variables on this task are the proportion of perseverative errors (e.g., total perseverative errors/total number of trials; Prop. Persev. Errors), and the total number of categories completed (Cat. Completed). These dependent variables were selected based on recent findings indicating that these variables most accurately discriminate between patients with frontal versus non-frontal lobe damage (Demakis, 2003).

Paper-pencil neuropsychological tests

Wisconsin Card Sorting Test (WCST-Card). This is the traditional 128-card version of the WCST (Heaton et al., 1993). In this task, participants sort cards to one of four reference cards in front of them according to one of three stimulus attributes - color, number or shape. Participants were not told beforehand how to sort the cards but they were provided verbal feedback from the examiner regarding the accuracy of their sort. (e.g., "correct" or "incorrect"). The category/stimulus attribute remained constant until ten consecutively correct sorts are made. After ten correct sorts, the category criterion changes. Each criterion (e.g., color, number & shape) appeared two times during the task for a total of six criterion changes. The test was concluded when 6 categories had been achieve or when 128 trials had been administered, whichever occurred first. The dependent variables are the proportion of perseverative errors (e.g., total perseverative errors/total number of trials; Prop. Persev. Errors), and the total number of categories completed (Cat. Completed).

Stroop (Card). The Card Stroop (Golden, 1978) is comprised of three conditions: word reading, color naming, and color-word naming. In the word naming condition, the participant is instructed to read the words on the stimulus sheet as quickly as possible. In the color naming condition, they are instructed to name the color that the XXXX's on the stimulus sheet are printed in as quickly as they can. In the color-word condition, they are instructed to name the color of the ink that the word is printed in, while ignoring what the word is, as quickly as they can. Each trial is 45 seconds and the dependent variable is the color-word interference (color naming minus color word naming) score (Interference).

Trail Making Test (TMT). The Trail Making Test (TMT; Reitan & Wolfson, 1985) is comprised of two subtests: Part-A and Part-B. In Part-A, the subject is required to draw lines on a page connecting twenty-five numbers in numerical sequence (e.g., 1-2-3-4…) as quickly as possible. In Part-B, the subject must draw lines alternating between numbers and letters in the appropriate sequence (e.g., 1–A–2–B–3-C…). Both Parts-A and -B assess rapid visual search and visuospatial sequencing; however, Part-B places additional demands on cognitive-set shifting (Spreen & Strauss, 1998) and mental flexibility (Bechtold, Horner, & Windham, 2001). The dependent variables for these tasks are the total number of seconds to complete Part A (TMT A) and Part B (TMT B).

Digit Span Test. The Digit Span test (Wechsler, 1991) is comprised of two separate elements: digit span forward and digit span backward. In the digit span forward subtest, the subject is verbally presented increasingly longer strings of single-digit numbers. Trial one consists of two digits (e.g., 7,3) and trial seven consists of 9 digits (e.g., 4,2,8,5,9,7,3,1,4). In the digit span forward task, the examiner reads the numbers and the subject repeats them back to the examiner in the same order in which they were presented. In the digit span backward task, trials are presented as they were in the digit span forward condition, but the subject must repeat the numbers backward (e.g., 3, 1, 9 =

9, 1, 3). A two-trial dyad was performed for each set of digits (e.g., set of two digits (trial 1), set of three digits (trial 2), etc.). For each set of digits, scoring is assessed in the following manner: 2-points if both trials are passed; 1-point if only one trial is passed; and 0-points if neither trial is passed. The dependent variables are the total number of points achieved across the forward (DSForward) and the backward (DSBackward) trials.

Paced Auditory Serial Addition Test (PASAT). The PASAT (Gronwall, 1977) is a test of information processing speed, working memory, and divided attention. Since this test has been demonstrated to be very sensitive to the presence of brain injury, it was included in the battery as a "gold standard" for later comparison. We employed a revised version of the original PASAT (Gronwall, 1977) described by Levin et al., (1987; PASAT-R), which presented audio-taped numbers, ranging from 1 to 9. Participants were instructed to add sequential numbers, such that they calculated the sum of each of the previous two numbers they heard. They provided verbal responses indicating their answers, which were recorded by the experimenter. Participants performed four trials of the PASAT-R, differing in rate of stimulus presentation, in the sequence: 2.8s, 2.4s, 2.0s, and 1.6s. Each trial contained 25 sequentially presented single-digit numbers. The dependent variable on this task is the total number correct across all trials (PASAT Total).

Digit Symbol Test. The Digit Symbol Test (Wechsler, 1991) consists of rows of rectangles where the top half of the rectangle has a number in it and the bottom half of the rectangle is empty. A key is provided at the top of the page with numbers (0-9) in the top portion of the rectangle and different symbols in the bottom portion of the rectangle. Each number is associated with its own unique symbol. The participant is to insert the appropriate symbol underneath each number in the box as quickly as they can. Like the

PASAT, this test has been shown to be very sensitive to detecting the presence of brain damage and again is considered a "gold standard" in TBI assessment. The dependent variable for this task is the total correct (DSymbol) in 120 seconds.

Modified version of the Neurobehavioral Rating Scale – Revised (NRS-R). We used a modified version of the NRS-R developed by Mathias & Coats (1999) that has been converted from a clinician rating format to a self-report format using a 5-point scale ranging from "never" (scored 0) to "very often" (scored 4). Higher scores represent greater difficulty within the specific cognitive or behavioral domain. Self-ratings and independent ratings of this measure were used to increase reliability of everyday functioning assessment. The dependent variable used on each measure is the total number of points on the self (NRS Self) and significant other (NRS Other) version of the survey.

Paper-pencil tests of everyday executive dysfunction

Behavioral Assessment of the Dysexecutive Syndrome. The Behavioral Assessment of the Dysexecutive Syndrome (BADS) is a battery of subtests that may be used independently to collect discrete information about the integrity of frontal lobe functioning, or the subtests may be used collectively to obtain a composite score purportedly indicative of gross frontal lobe functioning (Wilson et al., 1998). The dependent variables for this battery are the total raw scores for each subtest, and a composite score for the entire battery. Per the author's direction, the "Temporal Judgment" subtest was omitted due to cultural differences between the normative sample and "American users." The composite score was the sum of the profile scores from the remaining subtests (range 0-20; TotalProScore). Individual subtests of the BADS battery are described below.

Rule Shift Cards. This test requires the participant to respond correctly to a rule and to shift from one rule to another. A book of playing cards is placed in front of the subject and the cards are turned over one at a time and the participant says “yes” or “no” according to a rule that they have in front of them. In the first trial, the task rule is to say “yes” to a red playing card and “no” to a black playing card. In the second trial, the task rule changes and the participant says “yes” if the card is the same color as the previous one and “no” if it was not. The task is thought to measure response inhibition and the ability to maintain and shift cognitive set. The dependent variable on this task is the raw score (RSCTotal) which is the total number of errors and ranges from 0-40.

Action Program Test. This task was developed to provide subjects with a novel, practical test that requires a 5-step plan of action in order to solve the problem. The subject is presented with a 1-inch thick plastic rectangular stand. At one end of the stand is a large transparent bowl that is two-thirds full of water and is covered by a removable lid with a small hole in the center. A glass tube with a small cork in the bottom is set into the other end of the stand. To the left of the stand is placed a metal rod which is not quite long enough to reach the cork, and a small plastic tube that is threaded on the top. A threaded plastic cap that fits onto the threaded tube is lying next to the plastic tube. Participants are asked to get the cork out of the tube using any of the objects in front of them but without lifting up the stand, the tube or the water containing bowl and without touching the lid with their fingers. The plan requires the subject to sequentially progress through the five stages. If any stage is unsurpassable by the subject, the examiner provides a prompt. One point is deducted for each prompt given. There is no time limit for this task. The dependent variable on this task is the raw score (APRaw) which ranges from 0-5 and is based on the number of problem solving steps the participant completes.

Key Search Test. Subjects are presented with an 8 ½ X 11 piece of white paper with a 6 x 6 inch square in the center and a small black dot 3 inches below the square. Subjects are told to imagine that the square is a large field in which they have lost their keys. They are asked to draw a line, starting on the black dot, to show where they would walk to search the field to make absolutely sure they would find their keys. Scoring is based on the adequacy of the search pattern to find the keys with elements such as entering the field from a corner, vertical/horizontal searching versus concentric patterns receiving more points. The dependent variable on this task is the raw score (KSRaw) which ranges from 0-16.

Zoo Map Test. In this test, subjects are required to demonstrate how they would visit a series of designated locations on a map of a zoo. However, when planning the route, certain rules must be adhered to. The first trial consists of a high-demand version of the task in which the planning abilities of the subject are vigorously tested by requiring the subject to adhere to navigation rules while walking through the zoo (e.g., must start at entrance, finish at picnic area, can not use shaded pathways more than once, must visit fixed number of sites). Errors are made if the subject does not plan the route effectively. In the second trial, or low-demand trial, the subject is simply required to follow the instructions to produce an error-free performance. Directly following the instructions in the high-demand version of the test will maximize the total number of errors. Thus, in the high demand version, subjects have to structure their own plan unaided and in the low-demand version help is provided with the overall structure. The dependent variable on this task is the overall raw score (ZooTotal) which ranges from 0-16.

Modified Six Elements Test. This is a simplified version of the original Shallice and Burgess (1991) test, and involves the participants being given instructions to do three tasks (e.g., dictation, arithmetic and picture naming), each of which is divided into two parts referred to as parts "A" and "B." Thus, there are two dictation tasks, two sets of arithmetic problems, and two sets of pictures of objects that have to be named, for a total of six subtasks (elements). The participant is required to do something from each of the six subtasks within a 10-minute period. In addition, they are told that there is one rule which must not be broken: They are not allowed to do the two parts of the same task consecutively. For this task, it is not how well the participant performs in the individual components, rather the test measures how well participants organize themselves. Burgess (1997) confirmed that the Six Elements Test makes demands on a subject's ability to plan, organize, and monitor behavior. This task yields variables related to the number of subtasks attempted, the number of times the rule was broken for each type of task, and the maximum amount of time spent on any one subtask. The dependent variable on this task is the raw score (MSERaw) which ranges from 0-6.

The Dysexecutive Questionnaire (DEX). This is a 20-item questionnaire designed to assess a wide range of problems in patients with frontal lobe deficits. The questions sample four areas of functioning: (a) emotional or personality functioning, (b) motivation, (c) behavioral changes and (d) cognitive changes. Each item is scored on a five-point likert scale (0-4) based on the frequency that the symptom occurs (never-very often). One form is completed by the subject (self-rating) and another form is completed by a significant other (independent rating) who has contact with the individual each day. The raw score on both versions (DEX Self and DEX Other) ranges from 0-80 and serves as the primary dependent variable. The DEX is not used in the computation of the BADS total profile score.

Clinical assessment

The Beck Depression Inventory (BDI). The BDI is a widely recognized measure of depression which is used to assess the extent to which an individual currently exhibits or experiences each of the twenty-one behaviors, thoughts, or affective features commonly associated with depression (Beck, 1972). The dependent variable for this task is the total score for all items.

The State-Trait Anxiety Inventory (STAI). Given the potential confound that anxiety may yield on executive control, the STAI - form Y (Spielberger, 1977) was administered to provide information about the presence of anxiety at the time of testing (e.g., "state" anxiety). The test provides information about temporary conditions of "state" anxiety versus more long-standing conditions of "trait" anxiety. The test specifically addresses feelings of apprehension, tension, nervousness, and worry. The dependent variable is the total score for the "state" anxiety items.

The North American Adult Reading Test (NAART). The NAART (Blair & Spreen, 1989) is a reading test of 61 irregularly spelled words, and provides an estimate of premorbid intellectual functioning. The participant is presented with the word sheet and is instructed to read each word. The dependent variable on this test is the number of errors. The error score is used in a formula to derive an estimate of full scale IQ (FSIQ; 127.8 - .78[NAART errors]).

RESULTS

The collective sample (N=70) was comprised of 61 (87%) Caucasian, 4 (6%) African-American, 4 (6%) Hispanic and 1 (1%) Native-American participants. Control (n=24), mild TBI (n=20) and moderate/severe TBI (n=26) groups were compared with univariate ANOVAs with Bonferroni corrections on basic demographic features such as age, education, and NAART FSIQ (see Table 2). Analyses revealed no differences between groups on age or education; however, moderate/severe TBI participants achieved a significantly lower NAART FSIQ than mild participants. No association between group and gender was found. The NAART FSIQ findings notwithstanding, these groups appeared essentially equivalent on basic demographic features. There was no difference in time post-injury between mild and moderate/severe TBI groups, but as expected significant differences were observed on the injury severity variable 'duration of PTA,' Mann-Whitney $U(20,17) = 21.00$, $p < .001$. Results also showed that moderate/severe TBI participants endorsed greater depressive symptomatology than did controls, but the intensity of depressive symptomatology did not meet the clinical cutoff score for clinical depression recommended by Beck (1987) and Marsella, Sanborn, Kamboka, Shizuri, & Brennan, (1974). Our findings of depressive symptom endorsement are consistent with similar findings in the TBI literature (Garske & Thomas, 1992). On the STAI, moderate/severe TBI participants endorsed greater State anxiety than did mild TBI individuals, but the intensity of the anxiety was mild (see Table 2).

Table 2

Between group comparisons on demographic and emotional functioning variables

	Group Assignment			
	Controls	Mild TBI	Mod/Sev TBI	p
n	24	20	26	
Age				
M	35.13	33.95	40.73	>.05
SD	9.87	10.49	11.49	
Education				
M	14.04	15.03	13.90	>.05
SD	1.71	2.13	2.10	
NAART FSIQ				
M	107.03	109.20	101.91	<.05*
SD	7.33	8.62	11.18	
Gender (% M/F)				
	50/50	50/50	65/35	>.05
Time Post-injury (Months)				
M$^+$	N/A	20.80	25.58	>.05
Duration of PTA (Hours)				
M$^+$	N/A	11.55	27.76	<.01*
BDI				
M	3.67	6.15	10.54	<.01**
SD	4.14	6.00	8.61	
Mean STAI State				
M	27.25	26.67	34.07	<.05*
SD	5.23	7.61	10.75	
Table 2 Continued				
Mean STAI Trait				
M	27.31	33.33	35.86	>.05
SD	7.78	9.63	13.82	

Table 2 Continued

Note: M=Mean; SD=Standard deviation; NAART FSIQ=North American Adult Reading Test Full Scale IQ; PTA=Post-traumatic amnesia; BDI=Beck Depression Inventory; STAI=State Trait Anxiety Inventory; $^+$=Mean rank used for Mann-Whitney U statistic; *=Mod/Sev TBI significantly different from Mild TBI; **=Mod/Sev TBI significantly different from Controls.

TBI participants sustained their injuries in the following manner: 25 (54%) were involved in motor vehicle vs. motor vehicle accidents, 10 (22%) were involved in sport/recreational accidents, 6 (13%) were injured in motor vehicle vs. pedestrian accidents, and 5 (11%) were injured in falls. Eight (17%) TBI participants reported having been in litigation related to their accident in the past, one participant (2%) planned litigation in the future, but no participant was actively engaged in litigation at the time of testing.

Hypothesis/Prediction I

Since we were interested in determining if groups that differed in brain injury severity performed differently on individual tests of executive functioning/control, we predicted that controls would perform best and mild TBI participants would perform better than moderate/severe TBI participants. Given the univariate nature of our interest (Huberty & Morris, 1989), we conducted multiple one-way (3-Group) ANOVAs to determine if between group differences existed. Eta^2 was used as a measure of the proportion of variance accounted for by the independent variable (Howell, 1992). Following omnibus ANOVAs, we followed-up with pair-wise comparisons to determine which group differences accounted for the significant overall ANOVA. P-values for pair-wise comparisons are provided below in parentheses.

Cognitive Psychological Tests

Results indicated that moderate/severe TBI participants made a significantly greater proportion of errors on the N-Back (Low) task than did control participants ($p<.05$; see Table 3). On the N-Back (High) task, moderate/severe TBI participants made a significantly greater proportion or errors than did mild TBI ($p<.01$) and control participants ($p<.001$). On the computerized Stroop task, moderate/severe TBI participants made a significantly greater proportion of errors on the color-long incongruent trials than did mild TBI ($p<.05$) and control participants ($p<.05$); however, no between-group differences were observed on the color-short incongruent trials. Moderate/severe TBI participants achieved a significantly lower d' on the AX-Continuous Performance Test (CPT) long trials than did mild TBI ($p<.01$) and control participants ($p<.01$). They also obtained a significantly lower d' on the AX-CPT Interference long trials than did mild TBI ($p<.05$) and control participants ($p<.05$). Moderate/severe TBI participants completed significantly fewer categories on the computerized Wisconsin Card Sorting Test (WCST) than did mild TBI ($p<.01$) and control participants ($p<.01$). Moderate/severe TBI individuals made a significantly greater proportion of perseverative errors on the computerized WCST than did mild TBI ($p<.01$) and control participants ($p<.001$; see Figure 1 for z-scores).

Traditional Neuropsychological Tests

Analyses revealed no reliable group differences in the number of categories completed or proportion of perseverative errors on the card version of the WCST. On the traditional card version of the Stroop test, moderate/severe TBI participants achieved an interference score significantly lower than that of controls ($p<.01$). They took

Table 3

Between group comparisons for one-way (3-Group) ANOVAs

	Controls	Mild TBI	Mod/Sev TBI			
Dependent Variable	*M (SD)*	*M (SD)*	*M (SD)*	*F(2,67)*	*p*	*Eta*^{2}
		Cognitive Psychological Tests				
N-Back:						
Nback Low^A	.05 (.05)	.07 (.06)	.10 (.07)	3.53	$<.05$*	.10
Nback High^A	.15 (.07)	.16 (.07)	.25 (.00)	11.07	$<.01^+$	**.25**
Stroop (Computer):						
CL Incongruent^A	.03 (.06)	.04 (.07)	.15 (.22)	5.07	$<.01^+$	.13
CS Incongruent^A	.07 (.08)	.07 (.08)	.13 (.18)	2.05	$>.05$	.06
AX-CPT:						
d' AX NoInt Long^B	3.01 (.95)	3.05 (.80)	2.11 (1.2)	6.47	$<.01^+$	.16
d' AX Int Long^B	1.75 (.66)	1.81 (.79)	1.13 (.87)	5.62	$<.01^+$	.14
WCST (Computer):						
Cat. Completed^C	14.50 (2.1)	14.45 (2.5)	10.35 (5.93)	8.55	$<.01^+$	**.20**
Prop. Persev. Errors^D	.02 (.03)	.02 (.03)	.08 (.09)	10.09	$<.01^+$	**.23**
		Traditional Neuropsychological Tests				
WCST (Card):						
Cat. Completed^C	5.82 (.60)	5.93 (.26)	5.55 (.82)	1.50	$>.05$	.08
Prop. Persev. Errors^D	.09 (.04)	.09 (.05)	.11 (.06)	.58	$>.05$	.03

Table 3 Continued

Stroop (Card):						
Interference^E	-33.83 (9.8)	-28.60 (8.3)	-24.62 (8.5)	6.72	<.01*	.17
Trail Making Test:						
TMT A^F	21.83 (6.9)	26.05 (8.2)	36.38 (15.2)	11.51	<.01$^+$	**.26**
TMT B^F	49.13 (14.3)	66.20 (26.1)	93.35 (47.2)	11.39	<.01$^+$	**.25**
Digit Span:						
DSForward^G	10.21 (2.0)	10.85 (2.1)	9.73 (2.5)	1.43	>.05	.04
DSBackward^G	6.71 (2.1)	6.35 (1.7)	5.65 (2.1)	1.80	>.05	.05
PASAT:						
PASAT Total^H	77.38 (12.8)	71.40 (16.7)	57.42 (17.3)	10.58	<.01$^+$	**.24**
Digit Symbol:						
DSymbol^H	87.70 (17.3)	77.65 (18.6)	65.56 (15.7)	8.29	<.01*	**.22**
NRSself:						
NRS Self^G	19.21 (10.9)	29.90 (21.5)	44.42 (21.9)	11.38	<.01+	**.25**
NRSother:						
NRS Other^G	21.85 (13.6)	26.27 (19.4)	39.83 (15.2)	7.63	<.01+	**.21**
DEX Self:						
DEX Self^G	10.38 (6.9)	18.15 (12.5)	23.85 (14.8)	7.94	<.01*	.19
DEX Other:						
DEX Other^G	12.60 (12.3)	16.83 (13.6)	24.00 (12.5)	4.51	<.05*	.14

Table 3 Continued

			Tests of Everyday Executive Dysfunction			
BADS Rule Shift Cards:						
RSCTotal^{I}	.50 (.93)	1.10 (1.62)	1.88 (2.63)	3.33	<.05*	.09
BADS Action Program:						
APRaw^{G}	4.92 (.28)	4.90 (.31)	4.65 (.69)	2.31	>.05	.06
BADS Key Search:						
KSRaw^{G}	12.17 (2.4)	10.65 (3.7)	10.81 (3.6)	1.50	>.05	.04
BADS Zoo Map:						
ZooTotal^{G}	11.83 (3.8)	11.80 (4.2)	10.15 (5.0)	1.20	>.05	.03
BADS Modified Six Elements:						
MSERaw^{G}	5.63 (.92)	5.45 (1.1)	5.50 (1.0)	.18	>.05	.01
BADS Total Profile Score						
TotalProScore^{G}	16.83 (2.0)	16.35 (2.2)	15.50 (2.9)	2.0	>.05	.06

Note: ^{A}=Proportion of errors; ^{B}=d'; ^{C}=Categories completed; ^{D}=Proportion of perseverative errors; ^{E}=Interference/difference (Color naming minus color word naming score); ^{F}=Total Seconds; ^{G}=Total points achieved; ^{H}=Total correct; I=Total errors; *=Mod/Sev TBI significantly different from controls; $^{+}$=Mod/Sev TBI significantly different from mild TBI and controls. Boldface type indicates dependent variables that account for small amount of variance in the effect.

significantly longer to complete the Trail Making Test Part A when compared to mild TBI ($p<.01$) and control ($p<.001$) participants. Moderate/severe TBI participants required a longer period of time to complete the Trail Making Test Part B when compared to mild ($p<.05$) and control ($p<.001$) participants. There were no differences between groups on the Digit Span forward or backward subtests. On the PASAT, moderate/severe TBI participants achieved a significantly lower overall total score than did mild TBI participants ($p<.05$) or controls ($p<.001$). Moderate/severe TBI participants completed significantly fewer items on the Digit Symbol task than did controls ($p<.001$). On the modified version of the Neurobehavioral Rating Scale – Revised (NRS-R), moderate/severe TBI participants rated themselves as experiencing significantly greater cognitive and behavioral problems than did mild TBI participants ($p<.05$) or controls ($p<.001$). Informants of moderate/severe TBI participants rated them as having significantly greater cognitive and behavioral problems than did the informants of mild TBI participants ($p<.05$) or controls ($p<.01$). On the dysexecutive questionnaire, moderate/severe TBI participants rated themselves as experiencing significantly greater executive functioning deficits than did controls ($p<.01$), and informants of moderate/severe TBI participants rated them as having greater executive functioning deficits than did the informants of controls ($p<.05$; see Figure 2 for z-scores).

Tests of Everyday Executive Dysfunction

On the Behavioral Assessment of the Dysexecutive Syndrome (BADS) Rule Shift Cards subtest, moderate/severe TBI participants performed significantly worse than controls ($p<.05$). No significant differences between groups were found on the Action Profile Score (see Table 3; see Figure 3 for z-scores).

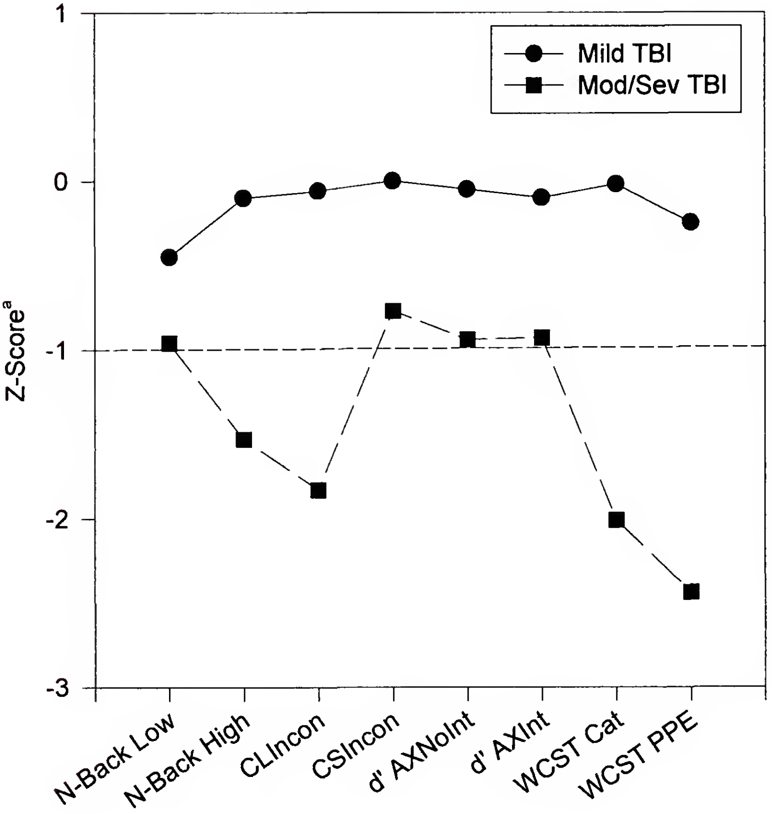

Figure 1. Z-scores for groups across cognitive psychological tests.

[a] Means and standard deviations are based on controls from this study. Z-scores that were originally positive but reflected greater impairment (e.g., proportion of errors) were changed to negative z-scores for continuity of data presentation.

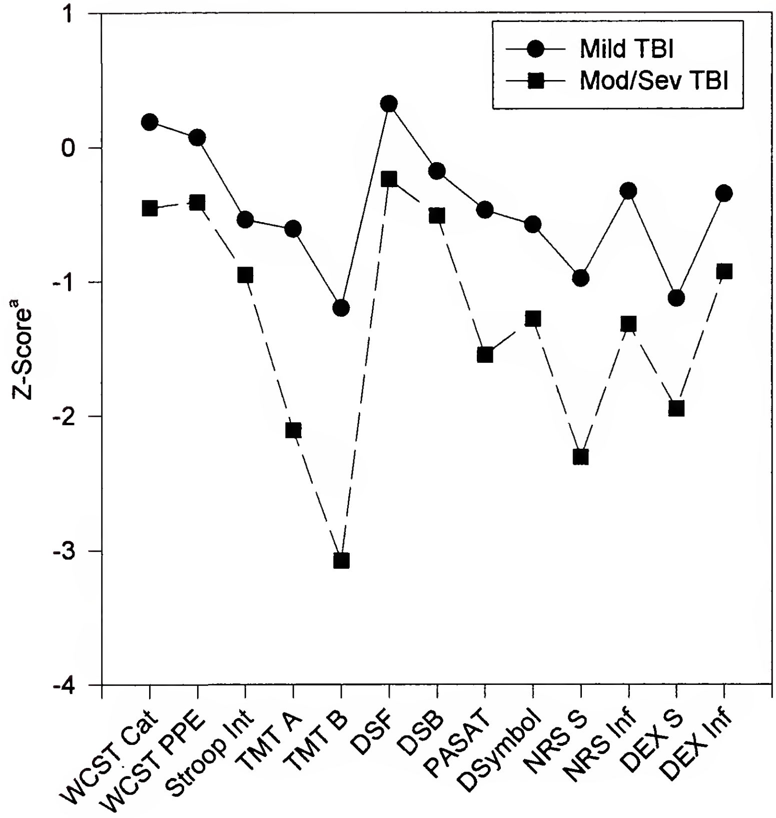

Figure 2. Z-scores for groups across traditional neuropsychological tests.

[a] Means and standard deviations are based on controls from this study. Z-scores that were originally positive but reflected greater impairment (e.g., proportion of errors) were changed to negative z-scores for continuity of data presentation.

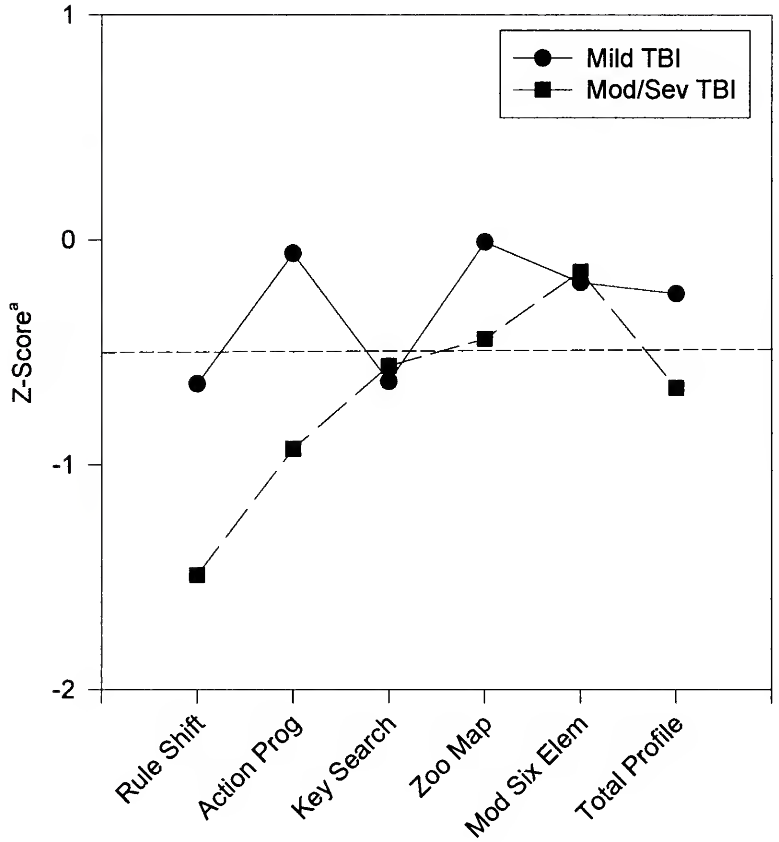

Figure 3. Z-scores for groups across tests of everyday executive dysfunction.

[a] Means and standard deviations are based on controls from this study. Z-scores that were originally positive but reflected greater impairment (e.g., proportion of errors) were changed to negative z-scores for continuity of data presentation.

Hypothesis/Prediction II

Here, our intentions were to define the operating characteristics of each test and then determine if positive predictive power differed as a function of test type (e.g., cognitive, neuropsychological, test of everyday executive dysfunction). We hypothesized that cognitive psychological tests would yield higher PPP because they are thought to be ‘purer’ measures of executive dysfunction than other tests. Specifically, we predicted that cognitive psychological tests of executive dysfunction would yield greater positive predictive power than traditional neuropsychological tests or tests of everyday executive dysfunction (e.g., Behavioral Assessment of the Dysexecutive Syndrome subtests).

Rather than the non-uniform method of using cutoff scores as indices of impaired test performance, all raw scores were converted to z-scores based on TBI and control participant data from the current sample. This method was preferred over the cutoff score approach because it uses local control data that are likely to match sample TBI participants with respect to important demographic features (e.g., geographic region, quality of education). In addition, the local control method permitted us to use the same cutoff threshold (e.g., 1.0, 1.5, 2.0 standard deviations) across all tests as opposed to published cutoff scores that may be unique to each test.

Prevalence rates of brain injury were determined for each test by dividing the number of participants with brain damage present by the total sample size. *Sensitivity* was computed by dividing the number of true positives by the total number of participants with brain injury. *Specificity* was computed by dividing the number of true negatives by the total number of participants without brain injury. *Positive predictive power* (PPP) was computed by dividing the number of true positives by the total number of participants with a positive sign (e.g., impaired test finding). *Negative predictive power* (NPP) was computed by dividing the number of true negatives by the total number of participants with a negative sign (e.g., non-impaired test finding). *Overall predictive power* (OPP) was computed by adding the total number of true positives and true negatives and dividing this sum by the total sample size. The *false negative rate* was computed by subtracting the negative predictive power coefficient from 1.0. *Odds ratios* (OR) were computed by dividing the dependent variable's sensitivity by its false positive rate. Predictive power estimates were interpreted using Cohen's (1988) assertion that coefficients of approximately .20, .50 and .80 are small, medium and large, respectively.

Operating Characteristics I. Control (n=24) and TBI (n=46) participants

The results from the statistical computations comparing test diagnostic accuracy between controls and all TBI participants are presented in Table 4. Given the large amount of data obtained in the current study, narrative descriptions will be provided only for the 1.0 standard deviation level of impairment (e.g., 16th %tile) for each dependent variable.

Cognitive psychological tests

N-Back (Low). This variable showed an OPP of 56%, and sensitivity and specificity estimates of 39% and 88%, respectively. These findings indicate that 61% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 86% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 43% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.1 times more likely to have brain dysfunction than a person who scores above that level.

N-Back (High). This variable showed an OPP of 57%, and sensitivity and specificity estimates of 46% and 79%, respectively. These findings indicate that 54% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 81% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 43% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.2 times more likely to have brain dysfunction than a person who scores above that level.

Stroop (Color-Long Incongruent). This variable showed an OPP of 51%, and sensitivity and specificity estimates of 33% and 88%, respectively. These findings indicate that 67% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 83% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 40% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.6 times more likely to have brain dysfunction than a person who scores above that level.

Stroop (Color-Short Incongruent). This variable showed an OPP of 44%, and sensitivity and specificity estimates of 26% and 79%, respectively. These findings indicate that 74% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 71% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 36% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.3 times more likely to have brain dysfunction than a person who scores above that level.

d' AX NoInt Long. This variable showed an OPP of 56%, and sensitivity and specificity estimates of 37% and 92%, respectively. These findings indicate that 63% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 90% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 43% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.4 times more likely to have brain dysfunction than a person who scores above that level.

d' AX Int Long. This variable showed an OPP of 50%, and sensitivity and specificity estimates of 35% and 79%, respectively. These findings indicate that 65% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 76% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 39% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.7 times more likely to have brain dysfunction than a person who scores above that level.

WCST Computer-Cat. Completed. This variable showed an OPP of 49%, and sensitivity and specificity estimates of 24% and 96%, respectively. These findings indicate that 76% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 92% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 40% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 5.7 times more likely to have brain dysfunction than a person who scores above that level.

WCST Computer- Prop. Persev. Errors. This variable showed an OPP of 59%, and sensitivity and specificity estimates of 39% and 96%, respectively. These findings indicate that 61% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 95% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 45% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.5 times more likely to have brain dysfunction than a person who scores above that level.

Traditional neuropsychological tests

WCST Card – Cat. Completed. This variable showed an OPP of 38%, and sensitivity and specificity estimates of 15% and 91%, respectively. These findings indicate that 85% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 80% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 31% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.7 times more likely to have brain dysfunction than a person who scores above that level.

WCST Card - Prop. Persev. Errors. This variable showed an OPP of 43%, and sensitivity and specificity estimates of 23% and 91%, respectively. These findings indicate that 77% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 86% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 33% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.5 times more likely to have brain dysfunction than a person who scores above that level.

Stroop – Interference. This variable showed an OPP of 53%, and sensitivity and specificity estimates of 37% and 83%, respectively. These findings indicate that 63% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 81% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 41% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one

Table 4

Operating characteristics for tests of executive dysfunction for controls (n=24) and TBI participants (n=46)

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
				Cognitive Psychological Tests										
N-Back	Nback Low	1.0	.66	.39	.88	.86	.43	.56	18	21	3	28	.61	3.1
	Nback Low	1.5	.66	.24	.96	.92	.40	.49	11	23	1	35	.76	5.7
	Nback Low	2.0	.66	.17	.96	.89	.38	.44	8	23	1	38	.83	4.2
	Nback High	1.0	.66	.46	.79	.81	.43	.57	21	19	5	25	.54	2.2
	Nback High	1.5	.66	.35	.96	.94	.43	.56	16	23	1	30	.65	8.4
	Nback High	2.0	.66	.22	.96	.91	.39	.47	10	23	1	36	.78	5.2
Stroop (Computer)	CL Incongruent	1.0	.66	.33	.88	.83	.40	.51	15	21	3	31	.67	2.6
	CL Incongruent	1.5	.66	.22	.88	.77	.37	.44	10	21	3	36	.78	1.7
	CL Incongruent	2.0	.66	.20	.88	.75	.36	.43	9	21	3	37	.80	1.6
	CS Incongruent	1.0	.66	.26	.79	.71	.36	.44	12	19	5	34	.74	1.3
	CS Incongruent	1.5	.66	.17	.92	.80	.37	.43	8	22	2	38	.83	2.1
	CS Incongruent	2.0	.66	.11	.92	.71	.35	.39	5	22	2	41	.89	1.3
AX-CPT	d’ AX NoInt Long	1.0	.66	.37	.92	.90	.43	.56	17	22	2	29	.63	4.4
	d’ AX NoInt Long	1.5	.66	.26	.92	.86	.39	.49	12	22	2	34	.74	3.1
	d’ AX NoInt Long	2.0	.66	.13	.04	.86	.02	.10	6	1	1	40	.87	3.1

Table 4 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
AX-CPT Interference	d’ AX Int Long	1.0	.66	.35	.79	.76	.39	.50	16	19	5	30	.65	1.7
	d’ AX Int Long	1.5	.66	.26	1.0	1.0	.41	.51	12	24	0	34	.74	0.0
	d’ AX Int Long	2.0	.66	.17	1.0	1.0	.39	.46	8	24	0	38	.83	0.0
WCST (Computer)	Cat. Completed	1.0	.66	.24	.96	.92	.40	.49	11	23	1	35	.76	5.7
	Cat. Completed	1.5	.66	.24	.96	.92	.40	.49	11	23	1	35	.76	5.7
	Cat. Completed	2.0	.66	.24	.96	.92	.40	.49	11	23	1	35	.76	5.7
	Prop. Persev. Errors	1.0	.66	.39	.96	.95	.45	.59	18	23	1	28	.61	9.4
	Prop. Persev. Errors	1.5	.66	.30	.96	.93	.42	.53	14	23	1	32	.70	7.3
	Prop. Persev. Errors	2.0	.66	.26	.96	.92	.40	.50	12	23	1	34	.74	6.3
Traditional Neuropsychological Tests														
WCST (Card)	Cat. Completed	1.0	.70	.15	.91	.80	.31	.38	4	10	1	22	.85	1.7
	Cat. Completed	1.5	.70	.08	.91	.67	.29	.32	2	10	1	24	.92	.85
	Cat. Completed	2.0	.70	.08	.91	.67	.29	.32	2	10	1	24	.92	.85
	Prop. Persev. Errors	1.0	.70	.23	.91	.86	.33	.43	6	10	1	20	.77	2.5
	Prop. Persev. Errors	1.5	.70	.15	.91	.80	.31	.38	4	10	1	22	.85	1.7
	Prop. Persev. Errors	2.0	.70	.15	.91	.80	.31	.38	4	10	1	22	.85	1.7
Stroop (Card)	Interference	1.0	.66	.37	.83	.81	.41	.53	17	20	4	29	.63	2.2
	Interference	1.5	.66	.17	.92	.80	.37	.43	8	22	2	38	.83	2.0
	Interference	2.0	.66	.09	1.0	1.0	.36	.40	4	24	0	42	.91	0.0

Table 4 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
Trails A	TMT A	1.0	.66	.52	.83	.86	.48	.63	24	20	4	22	.48	3.1
	TMT A	1.5	.66	.39	.92	.90	.44	.57	18	22	2	28	.61	4.7
	TMT A	2.0	.66	.30	.92	.88	.41	.51	14	22	2	32	.70	3.7
Trails B	TMT B	1.0	.66	.59	.83	.87	.51	.67	27	20	4	19	.41	3.5
	TMT B	1.5	.66	.54	.92	.93	.51	.67	25	22	2	21	.46	6.5
	TMT B	2.0	.66	.46	.92	.91	.47	.61	21	22	2	25	.54	5.5
Digit Span (Forward)	DSForward	1.0	.66	.33	.75	.71	.37	.47	15	18	6	31	.67	1.3
	DSForward	1.5	.66	.09	.92	.67	.34	.37	4	22	2	42	.91	1.0
	DSForward	2.0	.66	.04	1.0	1.0	.35	.37	2	24	0	44	.96	0.0
Digit Span (Backward)	DSBackward	1.0	.66	.26	.96	.92	.40	.50	12	23	1	34	.74	6.3
	DSBackward	1.5	.66	.11	1.0	1.0	.37	.41	5	24	0	41	.89	0.0
	DSBackward	2.0	.66	.04	1.0	1.0	.35	.37	2	24	0	44	.96	0.0
PASAT	PASAT Total	1.0	.66	.50	.79	.82	.45	.60	23	19	5	23	.50	2.4
	PASAT Total	1.5	.66	.35	.88	.84	.41	.53	16	21	3	30	.65	2.8
	PASAT Total	2.0	.66	.28	1.0	1.0	.42	.53	13	24	0	33	.72	0.0
Digit Symbol	DSymbol	1.0	.62	.50	.83	.83	.50	.62	19	19	4	19	.50	2.9
	DSymbol	1.5	.62	.26	.91	.83	.43	.51	10	21	2	28	.74	3.0
	DSymbol	2.0	.62	.16	.96	.86	.41	.46	6	22	1	32	.84	3.6
NRS Self	NRS Self	1.0	.66	.57	.83	.87	.50	.66	26	20	4	20	.44	3.4
	NRS Self	1.5	.66	.50	.96	.96	.50	.66	23	23	1	23	.50	12.0

Table 4 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
	NRS Self	2.0	.66	.41	1.0	1.0	.47	.61	19	24	0	27	.59	0.0
NRS Other	NRS Other	1.0	.66	.49	.90	.91	.47	.63	19	18	2	20	.51	4.9
	NRS Other	1.5	.66	.39	.90	.88	.43	.56	15	18	2	24	.62	3.9
	NRS Other	2.0	.66	.18	.95	.88	.37	.44	7	19	1	32	.82	3.6
DEX Self	DEX Self	1.0	.66	.46	.88	.88	.46	.60	21	21	3	25	.54	3.7
	DEX Self	1.5	.66	.37	.92	.90	.43	.56	17	22	2	29	.63	4.4
	DEX Self	2.0	.66	.35	.96	.94	.43	.56	16	23	1	30	.65	8.4
DEX Other	DEX Other	1.0	.66	.36	.85	.82	.41	.53	14	17	3	25	.64	2.4
	DEX Other	1.5	.66	.26	.95	.91	.40	.49	10	19	1	29	.74	5.1
	DEX Other	2.0	.66	.21	.95	.89	.38	.46	8	19	1	31	.80	4.1
				Tests of Everyday Executive Dysfunction										
BADS (Rule Shift)	RSCTotal	1.0	.66	.37	.92	.90	.43	.56	17	22	2	29	.63	4.4
	RSCTotal	1.5	.66	.37	.92	.90	.43	.56	17	22	2	29	.63	4.4
	RSCTotal	2.0	.66	.24	.96	.92	.40	.49	11	23	1	35	.76	5.7
BADS (Action pro)	APRaw	1.0	.66	.20	.92	.82	.37	.44	9	22	2	37	.80	2.4
	APRaw	1.5	.66	.20	.92	.82	.37	.44	9	22	2	37	.80	2.4
	APRaw	2.0	.66	.20	.92	.82	.37	.44	9	22	2	37	.80	2.4
BADS (Key Search)	KSRaw	1.0	.66	.37	.92	.90	.43	.56	17	22	2	29	.63	4.4
	KSRaw	1.5	.66	.33	.92	.88	.42	.53	15	22	2	31	.67	3.9

Table 4 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
	KSRaw	2.0	.66	.24	.96	.92	.40	.49	11	23	1	35	.76	5.7
BADS	ZooTotal	1.0	.66	.30	.88	.82	.40	.50	14	21	3	32	.70	2.4
(Zoo Map)	ZooTotal	1.5	.66	.17	.92	.80	.37	.43	8	22	2	38	.83	3.7
	ZooTotal	2.0	.66	.11	.96	.83	.36	.40	5	23	1	41	.89	2.6
BADS	MSERaw	1.0	.66	.15	.88	.70	.35	.40	7	21	3	39	.85	1.2
(Mod. 6 Elem.)	MSERaw	1.5	.66	.15	.88	.70	.35	.40	7	21	3	39	.85	1.2
	MSERaw	2.0	.66	.07	.92	.60	.34	.36	3	22	2	43	.94	.78
BADS	TotalProScore	1.0	.66	.26	.83	.75	.37	.46	12	20	4	34	.74	1.6
(Total)	TotalProScore	1.5	.66	.13	.96	.86	.37	.41	6	23	1	40	.87	3.1
	TotalProScore	2.0	.66	.07	1.0	1.0	.36	.39	3	24	0	43	.94	0.0

Note. Dep. Var.=dependent variable; Impair. (SD)=impairment level at 1.0, 1.5 or 2.0 standard deviations below the mean of controls in the current sample; Prev.=Prevalence; Sens.=sensitivity; Spec.=specificity; PPP=positive predictive power; NPP=negative predictive power; OPP=overall predictive power; TP=true positives; TN=true negatives; FP=false positives; FN=false negatives; FNr=false negative rate; OR=Odds ratio; CL=color long; CS=color short.

standard deviation or more below the mean of controls is 2.2 times more likely to have brain dysfunction than a person who scores above that level.

Trail Making Test Part A. This variable showed an OPP of 63%, and sensitivity and specificity estimates of 52% and 83%, respectively. These findings indicate that 48% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 86% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 48% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.1 times more likely to have brain dysfunction than a person who scores above that level.

Trail Making Test Part B. This variable showed an OPP of 67%, and sensitivity and specificity estimates of 59% and 83%, respectively. These findings indicate that 41% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 87% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 51% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.5 times more likely to have brain dysfunction than a person who scores above that level.

Digit Span Forward. This variable showed an OPP of 47%, and sensitivity and specificity estimates of 33% and 75%, respectively. These findings indicate that 67% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 71% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 37% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.3 times more likely to have brain dysfunction than a person who scores above that level.

Digit Span Backward. This variable showed an OPP of 50%, and sensitivity and specificity estimates of 26% and 96%, respectively. These findings indicate that 74% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 92% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 40% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 6.3 times more likely to have brain dysfunction than a person who scores above that level.

PASAT – Total. This variable showed an OPP of 60%, and sensitivity and specificity estimates of 50% and 79%, respectively. These findings indicate that 50% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 82% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 45% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Digit Symbol. This variable showed an OPP of 62%, and sensitivity and specificity estimates of 50% and 83%, respectively. These findings indicate that 50% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 83% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 50% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.9 times more likely to have brain dysfunction than a person who scores above that level.

Modified Neurobehavioral Rating Scale – Revised – Self Report. This variable showed an OPP of 87%, and sensitivity and specificity estimates of 57% and 83%, respectively. These findings indicate that 43% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 87% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 50% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.4 times more likely to have brain dysfunction than a person who scores above that level.

Modified Neurobehavioral Rating Scale – Revised – Informant Report . This variable showed an OPP of 63%, and sensitivity and specificity estimates of 49% and 90%, respectively. These findings indicate that 51% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 91% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 47% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.9 times more likely to have brain dysfunction than a person who scores above that level.

Dysexecutive Questionnaire – Self Report. This variable showed an OPP of 60%, and sensitivity and specificity estimates of 46% and 88%, respectively. These findings indicate that 54% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 88% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 46% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.7 times more likely to have brain dysfunction than a person who scores above that level.

Dysexecutive Questionnaire – Informant Report. This variable showed an OPP of 53%, and sensitivity and specificity estimates of 36% and 85%, respectively. These findings indicate that 64% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 82% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 41% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Tests of everyday executive dysfunction

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Rule Shift Cards. This variable showed an OPP of 56%, and sensitivity and specificity estimates of 37% and 92%, respectively. These findings indicate that 63% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 90% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 43% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.4 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Action Program Test. This variable showed an OPP of 44%, and sensitivity and specificity estimates of 20% and 92%, respectively. These findings indicate that 80% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 82% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 37% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Key Search Test. This variable showed an OPP of 56%, and sensitivity and specificity estimates of 37% and 92%, respectively. These findings indicate that 65% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 90% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 43% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.4 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Zoo Map Test. This variable showed an OPP of 50%, and sensitivity and specificity estimates of 30% and 88%, respectively. These findings indicate that 70% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 82% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 40% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a

TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Modified Six Elements Test. This variable showed an OPP of 40%, and sensitivity and specificity estimates of 15% and 88%, respectively. These findings indicate that 85% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 70% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 35% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.2 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Total Profile Score. This variable showed an OPP of 46%, and sensitivity and specificity estimates of 26% and 83%, respectively. These findings indicate that 74% of individuals with a TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a TBI. The NPP estimate indicated that 37% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.6 times more likely to have brain dysfunction than a person who scores above that level.

Operating Characteristics II: Control (n=24) and mild TBI (n=20) participants.

The results from the statistical computations comparing test diagnostic accuracy between controls and mild TBI participants are presented in Table 5. Given the large amount of data obtained in the current study, narrative descriptions will only be provided for the 1.0 standard deviation level of impairment (e.g., 16th %tile) for each dependent variable.

Cognitive psychological tests

N-Back (Low). This variable showed an OPP of 64%, and sensitivity and specificity estimates of 35% and 88%, respectively. These findings indicate that 65% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 70% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 62% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.8 times more likely to have brain dysfunction than a person who scores above that level.

N-Back (High). This variable showed an OPP of 55%, and sensitivity and specificity estimates of 25% and 79%, respectively. These findings indicate that 75% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 50% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 56% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.2 times more likely to have brain dysfunction than a person who scores above that level.

Stroop (Color-Long Incongruent). This variable showed an OPP of 55%, and sensitivity and specificity estimates of 15% and 88%, respectively. These findings indicate that 85% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 50% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 55% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.2 times more likely to have brain dysfunction than a person who scores above that level.

Stroop (Color-Short Incongruent). This variable showed an OPP of 52%, and sensitivity and specificity estimates of 20% and 79%, respectively. These findings indicate that 80% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 44% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 54% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is .96 times more likely to have brain dysfunction than a person who scores above that level.

d' AX NoInt Long. This variable showed an OPP of 59%, and sensitivity and specificity estimates of 20% and 92%, respectively. These findings indicate that 80% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 67% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

d' AX Int Long. This variable showed an OPP of 52%, and sensitivity and specificity estimates of 20% and 79%, respectively. These findings indicate that 80% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 44% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 54% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is .96 times more likely to have brain dysfunction than a person who scores above that level.

WCST Computer-Cat. Completed. This variable showed an OPP of 55%, and sensitivity and specificity estimates of 5% and 96%, respectively. These findings indicate that 95% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 50% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 55% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.2 times more likely to have brain dysfunction than a person who scores above that level.

WCST Computer- Prop. Persev. Errors. This variable showed an OPP of 61%, and sensitivity and specificity estimates of 20% and 96%, respectively. These findings indicate that 80% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 80% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 59% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.8 times more likely to have brain dysfunction than a person who scores above that level.

Traditional neuropsychological tests

WCST Card – Cat. Completed. This variable showed an OPP of 42%, and sensitivity and specificity estimates of 7% and 91%, respectively. These findings indicate that 93% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 50% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 42% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is .73 times more likely to have brain dysfunction than a person who scores above that level.

WCST Card - Prop. Persev. Errors. This variable showed an OPP of 50%, and sensitivity and specificity estimates of 20% and 91%, respectively. These findings indicate that 80% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 45% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.2 times more likely to have brain dysfunction than a person who scores above that level.

Table 5

Operating characteristics for tests of executive dysfunction for controls (n=24) and mild TBI participants (n=20)

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
Cognitive Psychological Tests														
N-Back	Nback Low	1.0	.45	.35	.88	.70	.62	.64	7	21	3	13	.65	2.8
	Nback Low	1.5	.45	.20	.96	.80	.59	.61	4	23	1	16	.80	4.8
	Nback Low	2.0	.45	.20	.96	.80	.59	.61	4	23	1	16	.80	4.8
	Nback High	1.0	.45	.25	.79	.50	.56	.55	5	19	5	15	.75	1.2
	Nback High	1.5	.45	.10	.96	.67	.56	.57	2	23	1	18	.90	2.4
	Nback High	2.0	.45	.05	.96	.50	.55	.55	1	23	1	19	.95	1.2
Stroop (Computer)	CL Incongruent	1.0	.45	.15	.88	.50	.55	.55	3	21	3	17	.85	1.2
	CL Incongruent	1.5	.45	.15	.88	.50	.55	.55	3	21	3	17	.85	1.2
	CL Incongruent	2.0	.45	.15	.88	.50	.55	.55	3	21	3	17	.85	1.2
	CS Incongruent	1.0	.45	.20	.79	.44	.54	.52	4	19	5	16	.80	.96
	CS Incongruent	1.5	.45	.15	.92	.60	.56	.57	3	22	2	17	.85	1.8
	CS Incongruent	2.0	.45	.00	.92	.00	.52	.50	0	22	2	20	1.0	0.0
AX-CPT	d’ AX NoInt Long	1.0	.45	.20	.92	.67	.58	.59	4	22	2	16	.80	2.4
	d’ AX NoInt Long	1.5	.45	.10	.92	.50	.55	.54	2	22	2	18	.90	1.2
	d’ AX NoInt Long	2.0	.45	.00	.96	.00	.53	.52	0	23	1	20	1.0	0.0

Table 5 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
AX-CPT	d' AX Int Long	1.0	.45	.20	.79	.44	.54	.52	4	19	5	16	.80	.96
Interference	d' AX Int Long	1.5	.45	.10	1.0	1.0	.57	.59	2	24	0	18	.90	0.0
	d' AX Int Long	2.0	.45	.05	1.0	1.0	.56	.57	1	24	19	19	.95	0.0
WCST	Cat. Completed	1.0	.45	.05	.96	.50	.55	.55	1	23	1	19	.95	1.2
(Computer)	Cat. Completed	1.5	.45	.05	.96	.50	.55	.55	1	23	1	19	.95	1.2
	Cat. Completed	2.0	.45	.05	.96	.50	.55	.55	1	23	1	19	.95	1.2
	Prop. Persev. Errors	1.0	.45	.20	.96	.80	.59	.61	4	23	1	16	.80	4.8
	Prop. Persev. Errors	1.5	.45	.10	.96	.67	.56	.57	2	23	1	18	.90	2.4
	Prop. Persev. Errors	2.0	.45	.10	.96	.67	.56	.57	2	23	1	18	.90	2.4
					Traditional Neuropsychological Tests									
WCST	Cat. Completed	1.0	.58	.07	.91	.50	.42	.42	1	10	1	14	.93	.73
(Card)	Cat. Completed	1.5	.58	.00	.91	.00	.40	.38	0	10	1	15	1.0	0.0
	Cat. Completed	2.0	.58	.00	.91	.00	.40	.38	0	10	1	15	1.0	0.0
	Prop. Persev. Errors	1.0	.58	.20	.91	.75	.45	.50	3	10	1	12	.80	2.2
	Prop. Persev. Errors	1.5	.58	.13	.91	.67	.43	.46	2	10	1	13	.87	1.5
	Prop. Persev. Errors	2.0	.58	.13	.91	.67	.43	.46	2	10	1	13	.87	1.5
Stroop	Interference	1.0	.45	.25	.83	.56	.57	.57	5	20	4	15	.75	1.5
(Card)	Interference	1.5	.45	.15	.92	.60	.56	.57	3	22	2	17	.85	1.8
	Interference	2.0	.45	.05	1.0	1.0	.56	.57	1	24	0	19	.95	0.0

Table 5 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
Trails A	TMT A	1.0	.45	.40	.83	.67	.63	.64	8	20	4	12	.60	2.4
	TMT A	1.5	.45	.20	.92	.67	.58	.60	4	22	2	16	.80	2.4
	TMT A	2.0	.45	.15	.92	.60	.56	.57	3	22	2	17	.85	1.2
Trails B	TMT B	1.0	.45	.40	.83	.67	.63	.64	8	20	4	12	.60	2.4
	TMT B	1.5	.45	.35	.92	.78	.63	.66	7	22	2	13	.65	4.2
	TMT B	2.0	.45	.30	.92	.75	.61	.64	6	22	2	14	.70	3.6
Digit Span (Forward)	DSForward	1.0	.45	.25	.75	.46	.55	.52	5	18	6	15	.75	1.0
	DSForward	1.5	.45	.00	.92	.00	.52	.50	0	22	2	20	1.0	0.0
	DSForward	2.0	.45	.00	1.0	.00	.55	.55	0	24	0	20	1.0	0.0
Digit Span (Backward)	DSBackward	1.0	.45	.15	.96	.75	.58	.59	3	23	1	17	.85	3.6
	DSBackward	1.5	.45	.05	1.0	1.0	.56	.57	1	24	0	19	.95	0.0
	DSBackward	2.0	.45	.00	1.0	.00	.55	.55	0	24	0	20	1.0	0.0
PASAT	PASAT Total	1.0	.45	.30	.79	.55	.58	.57	6	19	5	14	.70	1.4
	PASAT Total	1.5	.45	.25	.88	.63	.58	.59	5	21	3	15	.75	2.0
	PASAT Total	2.0	.45	.15	1.0	1.0	.59	.61	3	24	0	17	.85	0.0
Digit Symbol	DSymbol	1.0	.47	.45	.83	.69	.63	.65	9	19	4	11	.55	2.6
	DSymbol	1.5	.47	.20	.91	.67	.57	.58	4	21	2	16	.80	2.3
	DSymbol	2.0	.47	.05	.96	.50	.54	.53	1	22	1	19	.95	1.2
NRS Self	NRS Self	1.0	.45	.40	.83	.67	.63	.64	8	20	4	12	.60	2.4
	NRS Self	1.5	.45	.40	.96	.89	.66	.70	8	23	1	12	.60	9.6

Table 5 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
	NRS Self	2.0	.45	.25	1.0	1.0	.62	.66	5	24	0	15	.75	0.0
NRS Other	NRS Other	1.0	.43	.33	.90	.71	.64	.66	5	18	2	10	.67	3.3
	NRS Other	1.5	.43	.20	.90	.60	.60	.60	3	18	2	12	.80	2.0
	NRS Other	2.0	.43	.13	.95	.67	.59	.60	2	19	1	13	.87	2.7
DEX Self	DEX Self	1.0	.45	.35	.88	.70	.62	.64	7	21	3	13	.65	2.8
	DEX Self	1.5	.45	.25	.92	.71	.59	.61	5	22	2	15	.75	3.0
	DEX Self	2.0	.45	.25	.96	.83	.61	.64	5	23	1	15	.75	6.0
DEX Other	DEX Other	1.0	.43	.27	.85	.57	.61	.60	4	17	3	11	.73	1.8
	DEX Other	1.5	.43	.20	.95	.75	.61	.63	3	19	1	12	.80	4.0
	DEX Other	2.0	.43	.13	.95	.67	.59	.60	2	19	1	13	.87	2.7
Tests of Everyday Executive Dysfunction														
BADS (Rule Shift)	RSCTotal	1.0	.45	.30	.92	.75	.61	.64	6	22	2	14	.70	3.6
	RSCTotal	1.5	.45	.30	.92	.75	.61	.64	6	22	2	14	.70	3.6
	RSCTotal	2.0	.45	.15	.96	.75	.58	.59	3	23	1	17	.85	3.6
BADS (Action pro)	APRaw	1.0	.45	.10	.92	.50	.55	.55	2	22	2	18	.90	1.2
	APRaw	1.5	.45	.10	.92	.50	.55	.55	2	22	2	18	.90	1.2
	APRaw	2.0	.45	.10	.92	.50	.55	.55	2	22	2	18	.90	1.2
BADS (Key Search)	KSRaw	1.0	.45	.35	.92	.78	.63	.66	7	22	2	13	.65	4.2
	KSRaw	1.5	.45	.30	.92	.75	.61	.64	6	22	2	14	.70	3.6

Table 5 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
	KSRaw	2.0	.45	.25	.96	.83	.61	.64	5	23	1	15	.75	6.0
BADS	ZooTotal	1.0	.45	.25	.88	.63	.58	.59	5	21	3	15	.75	2.0
(Zoo Map)	ZooTotal	1.5	.45	1.0	.92	.50	.55	.55	2	22	2	18	.90	1.2
	ZooTotal	2.0	.45	.05	.96	.50	.55	.55	1	23	1	19	.95	1.2
BADS	MSERaw	1.0	.45	.20	.88	.57	.57	.57	4	21	3	16	.80	1.6
(Mod. 6 Elem.)	MSERaw	1.5	.45	.20	.88	.57	.57	.57	4	21	3	16	.80	1.6
	MSERaw	2.0	.45	.05	.92	.33	.54	.52	1	22	2	19	.95	.60
BADS	TotalProScore	1.0	.45	.25	.83	.56	.57	.57	5	20	4	15	.75	1.5
(Total)	TotalProScore	1.5	.45	.05	.96	.50	.55	.55	1	23	1	19	.95	1.2
	TotalProScore	2.0	.45	.05	1.0	1.0	.56	.57	1	24	0	19	.95	0.0

Note. Dep. Var.=dependent variable; Impair. (SD)=impairment level at 1.0, 1.5 or 2.0 standard deviations below the mean of controls in the current sample; Prev.=Prevalence; Sens.=sensitivity; Spec.=specificity; PPP=positive predictive power; NPP=negative predictive power; OPP=overall predictive power; TP=true positives; TN=true negatives; FP=false positives; FN=false negatives; FNr=false negative rate; OR=Odds Ration; CL=color long; CS=color short.

Stroop – Interference. This variable showed an OPP of 57%, and sensitivity and specificity estimates of 25% and 83%, respectively. These findings indicate that 75% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 56% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 57% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.5 times more likely to have brain dysfunction than a person who scores above that level.

Trail Making Test Part A. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 40% and 83%, respectively. These findings indicate that 60% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 67% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 63% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Trail Making Test Part B. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 40% and 83%, respectively. These findings indicate that 60% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 67% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 63%

of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Digit Span Forward. This variable showed an OPP of 52%, and sensitivity and specificity estimates of 25% and 75%, respectively. These findings indicate that 75% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 46% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 55% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.0 time more likely to have brain dysfunction than a person who scores above that level.

Digit Span Backward. This variable showed an OPP of 59%, and sensitivity and specificity estimates of 15% and 96%, respectively. These findings indicate that 85% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.6 times more likely to have brain dysfunction than a person who scores above that level.

PASAT – Total. This variable showed an OPP of 57%, and sensitivity and specificity estimates of 30% and 79%, respectively. These findings indicate that 70% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 55% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.4 times more likely to have brain dysfunction than a person who scores above that level.

Digit Symbol. This variable showed an OPP of 65%, and sensitivity and specificity estimates of 45% and 83%, respectively. These findings indicate that 55% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 69% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 63% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.6 times more likely to have brain dysfunction than a person who scores above that level.

Modified Neurobehavioral Rating Scale – Revised – Self Report. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 40% and 83%, respectively. These findings indicate that 60% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 67% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild

TBI. The NPP estimate indicated that 63% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.4 times more likely to have brain dysfunction than a person who scores above that level.

Modified Neurobehavioral Rating Scale – Revised – Significant Other Report . This variable showed an OPP of 66%, and sensitivity and specificity estimates of 33% and 90%, respectively. These findings indicate that 67% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 71% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 64% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.3 times more likely to have brain dysfunction than a person who scores above that level.

Dysexecutive Questionnaire – Self Report. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 35% and 88%, respectively. These findings indicate that 65% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 70% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 62% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.8 times more likely to have brain dysfunction than a person who scores above that level.

Dysexecutive Questionnaire – Significant Other Report. This variable showed an OPP of 60%, and sensitivity and specificity estimates of 27% and 85%, respectively. These findings indicate that 73% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 57% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 61% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.8 times more likely to have brain dysfunction than a person who scores above that level.

Tests of everyday executive dysfunction

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Rule Shift Cards. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 30% and 92%, respectively. These findings indicate that 70% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 61% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.6 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Action Program Test. This variable showed an OPP of 55%, and sensitivity and specificity estimates of 10% and 92%, respectively. These findings indicate that 90% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 50% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 55% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.2 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Key Search Test. This variable showed an OPP of 66%, and sensitivity and specificity estimates of 35% and 92%, respectively. These findings indicate that 65% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 78% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 63% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.2 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Zoo Map Test. This variable showed an OPP of 59%, and sensitivity and specificity estimates of 25% and 88%, respectively. These findings indicate that 75% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 63% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.0 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Modified Six Elements Test. This variable showed an OPP of 57%, and sensitivity and specificity estimates of 20% and 88%, respectively. These findings indicate that 80% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 57% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 57% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.6 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Total Profile Score. This variable showed an OPP of 57%, and sensitivity and specificity estimates of 25% and 83%, respectively. These findings indicate that 75% of individuals with a mild TBI scored in the normal range. The PPP estimate indicated that 56% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a mild TBI. The NPP estimate indicated that 57% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a mild TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.5 times more likely to have brain dysfunction than a person who scores above that level.

Operating Characteristics III: Control (n=24) and moderate/severe TBI (n=26) participants.

The results from the statistical computations comparing the diagnostic accuracy between controls and moderate/severe TBI participants are presented in Table 6. Again, given the large amount of data obtained in the current study, narrative descriptions will only be provided for the 1.0 standard deviation level of impairment (e.g., 16th %tile) for each dependent variable.

Cognitive psychological tests

N-Back (Low). This variable showed an OPP of 64%, and sensitivity and specificity estimates of 42% and 88%, respectively. These findings indicate that 58% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 79% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.4 times more likely to have brain dysfunction than a person who scores above that level.

N-Back (High). This variable showed an OPP of 70%, and sensitivity and specificity estimates of 62% and 79%, respectively. These findings indicate that 38% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 76% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 66% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.0 times more likely to have brain dysfunction than a person who scores above that level.

Stroop (Color-Long Incongruent). This variable showed an OPP of 66%, and sensitivity and specificity estimates of 46% and 88%, respectively. These findings indicate that 54% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 80% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 60% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.7 times more likely to have brain dysfunction than a person who scores above that level.

Stroop (Color-Short Incongruent). This variable showed an OPP of 54%, and sensitivity and specificity estimates of 31% and 79%, respectively. These findings indicate that 69% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 62% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 51% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.5 times more likely to have brain dysfunction than a person who scores above that level.

d' AX NoInt Long. This variable showed an OPP of 70%, and sensitivity and specificity estimates of 50% and 92%, respectively. These findings indicate that 50% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 87% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 63% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 6.0 times more likely to have brain dysfunction than a person who scores above that level.

d' AX Int Long. This variable showed an OPP of 62%, and sensitivity and specificity estimates of 46% and 79%, respectively. These findings indicate that 54% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 71% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.2 times more likely to have brain dysfunction than a person who scores above that level.

WCST Computer-Cat. Completed. This variable showed an OPP of 66%, and sensitivity and specificity estimates of 38% and 96%, respectively. These findings indicate that 62% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 91% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 59% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 9.2 times more likely to have brain dysfunction than a person who scores above that level.

WCST Computer- Prop. Persev. Errors. This variable showed an OPP of 74%, and sensitivity and specificity estimates of 54% and 96%, respectively. These findings indicate that 46% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 93% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 66% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 13.0 times more likely to have brain dysfunction than a person who scores above that level.

Traditional neuropsychological tests

WCST Card – Cat. Completed. This variable showed an OPP of 59%, and sensitivity and specificity estimates of 27% and 91%, respectively. These findings indicate that 73% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 56% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.0 times more likely to have brain dysfunction than a person who scores above that level.

WCST Card - Prop. Persev. Errors. This variable showed an OPP of 59%, and sensitivity and specificity estimates of 27% and 91%, respectively. These findings indicate that 73% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 56% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.0 times more likely to have brain dysfunction than a person who scores above that level.

Table 6

Operating characteristics for tests of executive dysfunction for controls (n=24) and moderate/severe TBI participants (n=26)

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
				Cognitive Psychological Tests										
N-Back	Nback Low	1.0	.52	.42	.88	.79	.58	.64	11	21	3	15	.58	3.4
	Nback Low	1.5	.52	.27	.96	.88	.55	.60	7	23	1	19	.73	6.5
	Nback Low	2.0	.52	.15	.96	.80	.51	.54	4	23	1	22	.85	3.7
	Nback High	1.0	.52	.62	.79	.76	.66	.70	16	19	1	10	.38	3.0
	Nback High	1.5	.52	.54	.96	.93	.66	.74	14	23	1	12	.46	13.0
	Nback High	2.0	.52	.35	.96	.90	.58	.64	9	23	1	17	.65	8.3
Stroop (Computer)	CL Incongruent	1.0	.52	.46	.88	.80	.60	.66	12	21	3	14	.54	3.7
	CL Incongruent	1.5	.52	.27	.88	.70	.53	.56	7	21	3	19	.73	2.2
	CL Incongruent	2.0	.52	.23	.88	.67	.51	.54	6	21	3	20	.77	1.9
	CS Incongruent	1.0	.52	.31	.79	.62	.51	.54	8	19	5	18	.69	1.5
	CS Incongruent	1.5	.52	.19	.92	.71	.51	.54	5	22	2	21	.81	2.3
	CS Incongruent	2.0	.52	.19	.92	.71	.51	.54	5	22	2	21	.81	2.3
AX-CPT	d' AX NoInt Long	1.0	.52	.50	.92	.87	.63	.70	13	22	2	13	.50	6.0
	d' AX NoInt Long	1.5	.52	.38	.92	.83	.58	.64	10	22	2	16	.62	4.6
	d' AX NoInt Long	2.0	.52	.23	.96	.86	.53	.58	6	23	1	20	.77	5.5

Table 6 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
AX-CPT Interference	d’ AX Int Long	1.0	.52	.46	.79	.71	.58	.62	12	19	5	14	.54	2.2
	d’ AX Int Long	1.5	.52	.38	1.0	1.0	.60	.68	10	24	0	16	.62	0.0
	d’ AX Int Long	2.0	.52	.27	1.0	1.0	.56	.62	7	24	0	19	.73	0.0
WCST (Computer)	Cat. Completed	1.0	.52	.38	.96	.91	.59	.66	10	23	1	16	.62	9.2
	Cat. Completed	1.5	.52	.38	.96	.91	.59	.66	10	23	1	16	.62	9.2
	Cat. Completed	2.0	.52	.38	.96	.91	.59	.66	10	23	1	16	.62	9.2
	Prop. Persev. Errors	1.0	.52	.54	.96	.93	.66	.74	14	23	1	12	.46	13.0
	Prop. Persev. Errors	1.5	.52	.46	.96	.92	.62	.70	12	23	1	14	.54	11.0
	Prop. Persev. Errors	2.0	.52	.38	.96	.91	.59	.66	10	23	1	16	.62	9.2
Traditional Neuropsychological Tests														
WCST (Card)	Cat. Completed	1.0	.50	.27	.91	.75	.56	.59	3	10	1	8	.73	3.0
	Cat. Completed	1.5	.50	.18	.91	.67	.53	.55	2	10	1	9	.82	2.0
	Cat. Completed	2.0	.50	.18	.91	.67	.53	.55	2	10	1	9	.82	2.0
	Prop. Persev. Errors	1.0	.50	.27	.91	.75	.56	.59	3	10	1	8	.73	3.0
	Prop. Persev. Errors	1.5	.50	.18	.91	.67	.53	.55	2	10	1	9	.82	2.0
	Prop. Persev. Errors	2.0	.50	.18	.91	.67	.53	.55	2	10	1	9	.82	2.0
Stroop (Card)	Interference	1.0	.52	.46	.83	.75	.59	.64	12	20	4	14	.54	2.8
	Interference	1.5	.52	.19	.92	.71	.51	.54	5	22	2	21	.81	2.3
	Interference	2.0	.52	.12	1.0	1.0	.51	.54	3	24	0	23	.88	0.0

Table 6 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
Trails A	TMT A	1.0	.52	.62	.83	.80	.67	.72	16	20	4	10	.38	3.7
	TMT A	1.5	.52	.54	.92	.88	.65	.72	14	22	2	12	.46	6.5
	TMT A	2.0	.52	.42	.92	.85	.59	.66	11	22	2	15	.58	5.0
Trails B	TMT B	1.0	.52	.73	.83	.83	.74	.78	19	20	4	7	.27	4.4
	TMT B	1.5	.52	.69	.92	.90	.73	.80	18	22	2	8	.31	8.3
	TMT B	2.0	.52	.58	.92	.88	.67	.74	15	22	2	11	.42	6.9
Digit Span (Forward)	DSForward	1.0	.52	.38	.75	.63	.53	.56	10	18	6	16	.62	1.5
	DSForward	1.5	.52	.15	.92	.67	.50	.52	4	22	2	22	.85	1.9
	DSForward	2.0	.52	.08	1.0	1.0	.50	.52	2	24	0	24	.92	0.0
Digit Span (Backward)	DSBackward	1.0	.52	.35	.96	.90	.58	.64	9	23	1	17	.65	8.3
	DSBackward	1.5	.52	.15	1.0	1.0	.52	.56	4	24	0	22	.85	0.0
	DSBackward	2.0	.52	.08	1.0	1.0	.50	.52	2	24	0	24	.92	0.0
PASAT	PASAT Total	1.0	.52	.65	.79	.77	.68	.72	17	19	5	9	.35	3.1
	PASAT Total	1.5	.52	.42	.88	.79	.58	.64	11	21	3	15	.58	3.4
	PASAT Total	2.0	.52	.38	1.0	1.0	.60	.68	10	24	0	16	.62	0.0
Digit Symbol	DSymbol	1.0	.44	.56	.83	.71	.70	.71	10	19	4	8	.44	3.2
	DSymbol	1.5	.44	.33	.91	.75	.64	.66	6	21	2	12	.67	3.8
	DSymbol	2.0	.44	.28	.96	.83	.63	.66	5	22	1	13	.72	6.4
NRS Self	NRS Self	1.0	.52	.69	.83	.82	.71	.76	18	20	4	8	.31	4.2
	NRS Self	1.5	.52	.58	.96	.94	.68	.76	15	23	1	11	.42	13.9

Table 6 Continued

Test	Dep. Var.	Impair. (SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
	NRS Self	2.0	.52	.54	1.0	1.0	.67	.76	14	24	0	12	.46	0.0
NRS Other	NRS Other	1.0	.55	.58	.90	.88	.64	.73	14	18	2	10	.42	5.8
	NRS Other	1.5	.55	.50	.90	.86	.60	.68	12	18	2	12	.50	5.0
	NRS Other	2.0	.55	.21	.95	.83	.50	.55	5	19	1	19	.79	4.2
DEX Self	DEX Self	1.0	.52	.54	.88	.82	.64	.70	14	21	3	12	.46	4.3
	DEX Self	1.5	.52	.46	.92	.86	.61	.68	12	22	2	14	.54	5.5
	DEX Self	2.0	.52	.42	.96	.92	.61	.68	11	23	1	15	.58	10.2
DEX Other	DEX Other	1.0	.55	.42	.85	.77	.55	.61	10	17	3	14	.58	2.8
	DEX Other	1.5	.55	.29	.95	.88	.53	.59	7	19	1	17	.71	5.8
	DEX Other	2.0	.55	.25	.95	.86	.51	.57	6	19	1	18	.75	5.0
					Tests of Everyday Executive Dysfunction									
BADS (Rule Shift)	RSCTotal	1.0	.52	.42	.92	.85	.59	.66	11	22	2	15	.58	5.1
	RSCTotal	1.5	.52	.42	.92	.85	.59	.66	11	22	2	15	.58	5.1
	RSCTotal	2.0	.52	.31	.96	.89	.56	.62	8	23	1	18	.69	7.4
BADS (Action Pro.)	APRaw	1.0	.52	.27	.92	.78	.54	.58	7	22	2	19	.73	3.2
	APRaw	1.5	.52	.27	.92	.78	.54	.58	7	22	2	19	.73	3.2
	APRaw	2.0	.52	.27	.92	.78	.54	.58	7	22	2	19	.73	3.2
BADS (Key Search)	KSRaw	1.0	.52	.38	.92	.83	.58	.64	10	22	2	16	.62	4.6
	KSRaw	1.5	.52	.35	.92	.82	.56	.62	9	22	2	17	.65	4.2

Table 6 Continued

Test	Dep. Var.	Impair.	(SD)	Prev.	Sens.	Spec.	PPP	NPP	OPP	TP	TN	FP	FN	FNr	OR
	KSRaw	2.0	.52	.23	.96	.86	.53	.58	6	23	1	20	.77	5.5	
BADS	ZooTotal	1.0	.52	.35	.88	.75	.55	.60	9	21	3	17	.65	2.8	
(Zoo Map)	ZooTotal	1.5	.52	.23	.92	.75	.52	.56	6	22	2	20	.77	2.8	
	ZooTotal	2.0	.52	.15	.96	.80	.51	.54	4	23	1	22	.85	3.7	
BADS	MSERaw	1.0	.52	.12	.88	.50	.48	.48	3	21	3	23	.88	.92	
(Mod. 6 Elem.)	MSERaw	1.5	.52	.12	.88	.50	.48	.48	3	21	3	23	.88	.92	
	MSERaw	2.0	.52	.08	.92	.50	.48	.48	2	22	2	24	.92	.92	
BADS	TotalProScore	1.0	.52	.27	.83	.64	.51	.54	7	20	4	19	.73	1.6	
(Total)	TotalProScore	1.5	.52	.19	.96	.83	.52	.56	5	23	1	21	.81	4.6	
	TotalProScore	2.0	.52	.08	1.0	1.0	.50	.52	2	24	0	24	.92	0.0	

Note. Dep. Var.=dependent variable; Impair. (SD)=impairment level at 1.0, 1.5 or 2.0 standard deviations below the mean of controls in the current sample; Prev.=Prevalence; Sens.=sensitivity; Spec.=specificity; PPP=positive predictive power; NPP=negative predictive power; OPP=overall predictive power; TP=true positives; TN=true negatives; FP=false positives; FN=false negatives; FNr=false negative rate; CL=color long; CS=color short.

Stroop – Interference. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 46% and 83%, respectively. These findings indicate that 54% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 59% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.8 times more likely to have brain dysfunction than a person who scores above that level.

Trail Making Test Part A. This variable showed an OPP of 72%, and sensitivity and specificity estimates of 62% and 83%, respectively. These findings indicate that 38% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 80% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 67% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.7 times more likely to have brain dysfunction than a person who scores above that level.

Trail Making Test Part B. This variable showed an OPP of 78%, and sensitivity and specificity estimates of 73% and 83%, respectively. These findings indicate that 27% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 83% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 74% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.4 times more likely to have brain dysfunction than a person who scores above that level.

Digit Span Forward. This variable showed an OPP of 56%, and sensitivity and specificity estimates of 38% and 75%, respectively. These findings indicate that 62% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 63% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 53% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.5 times more likely to have brain dysfunction than a person who scores above that level.

Digit Span Backward. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 35% and 96%, respectively. These findings indicate that 65% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 90% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 8.3 times more likely to have brain dysfunction than a person who scores above that level.

PASAT – Total. This variable showed an OPP of 72%, and sensitivity and specificity estimates of 65% and 79%, respectively. These findings indicate that 35% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 77% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 68% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.1 times more likely to have brain dysfunction than a person who scores above that level.

Digit Symbol. This variable showed an OPP of 71%, and sensitivity and specificity estimates of 56% and 83%, respectively. These findings indicate that 44% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 71% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 70% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.2 times more likely to have brain dysfunction than a person who scores above that level.

Modified Neurobehavioral Rating Scale – Revised – Self Report. This variable showed an OPP of 76%, and sensitivity and specificity estimates of 69% and 83%, respectively. These findings indicate that 31% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 82% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 71% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.2 times more likely to have brain dysfunction than a person who scores above that level.

Modified Neurobehavioral Rating Scale – Revised – Significant Other Report. This variable showed an OPP of 73%, and sensitivity and specificity estimates of 58% and 90%, respectively. These findings indicate that 42% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 88% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 64% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 5.8 times more likely to have brain dysfunction than a person who scores above that level.

Dysexecutive Questionnaire – Self Report. This variable showed an OPP of 70%, and sensitivity and specificity estimates of 54% and 88%, respectively. These findings indicate that 46% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 82% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 64% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.3 times more likely to have brain dysfunction than a person who scores above that level.

Dysexecutive Questionnaire – Significant Other Report. This variable showed an OPP of 61%, and sensitivity and specificity estimates of 42% and 85%, respectively. These findings indicate that 58% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 77% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 55% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.8 times more likely to have brain dysfunction than a person who scores above that level.

Tests of everyday executive dysfunction

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Rule Shift Cards. This variable showed an OPP of 66%, and sensitivity and specificity estimates of

42% and 92%, respectively. These findings indicate that 58% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 85% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 59% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 5.1 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Action Program Test. This variable showed an OPP of 58%, and sensitivity and specificity estimates of 27% and 92%, respectively. These findings indicate that 73% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 78% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 54% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 3.2 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Key Search Test. This variable showed an OPP of 64%, and sensitivity and specificity estimates of 38% and 92%, respectively. These findings indicate that 62% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 83% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 58% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 4.6 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Zoo Map Test. This variable showed an OPP of 60%, and sensitivity and specificity estimates of 35% and 88%, respectively. These findings indicate that 65% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 75% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 55% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 2.8 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Modified Six Elements Test. This variable showed an OPP of 48%, and sensitivity and specificity estimates of 12% and 88%, respectively. These findings indicate that 88% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 50% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 48% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI.

For this variable, an individual who scores one standard deviation or more below the mean of controls is .92 times more likely to have brain dysfunction than a person who scores above that level.

Behavioral Assessment of the Dysexecutive Syndrome (BADS) – Total Profile Score. This variable showed an OPP of 54%, and sensitivity and specificity estimates of 27% and 83%, respectively. These findings indicate that 73% of individuals with a moderate/severe TBI scored in the normal range. The PPP estimate indicated that 64% of participants who obtained a score in the impaired range (test positive) were correctly classified as having sustained a moderate/severe TBI. The NPP estimate indicated that 51% of control participants achieved a score in the unimpaired range (test negative) and were correctly classified as not having sustained a moderate/severe TBI. For this variable, an individual who scores one standard deviation or more below the mean of controls is 1.6 times more likely to have brain dysfunction than a person who scores above that level.

We used omnibus one-way ANOVAs to determine if cognitive psychological tests yielded higher positive predictive power than traditional neuropsychological tests or tests of everyday executive dysfunction. Results indicated no significant differences in positive predictive power for type of test in cases of mild ($p>.05$) and moderate/severe TBI ($p>.05$).

Hypothesis/Prediction III

We hypothesized that a weighted linear combination of predictor variables would be useful in differentiating groups. Specifically, we predicted that a weighted linear combination of predictor variables that could discriminate group membership would include a greater number of cognitive psychological tests than traditional neuropsychological tests or tests of everyday executive dysfunction. We performed a 3-group stepwise predictive discriminant function analysis using the two tests with the highest positive predictive power and odds ratio from cognitive (e.g., computerized WCST Proportion of Perseverative Errors, and computerized WCST categories completed), traditional neuropsychological (e.g., Digit Span Backwards, and Dysexecutive Questionnaire Self Report), and everyday executive dysfunction (e.g., BADS Rule Shift Cards and Key Search Task) tests to develop a weighted linear combination of predictor variables that would best discriminate group membership. The variables used were selected from the 1.0 level of impairment for the entire sample ($\underline{N} = 70$).

Of the original 70 cases, six were identified as multivariate outliers – discontinuously performing more than three standard deviations from the respective mean of the entire sample on one or more variables. All six of these cases were from the moderate/severe TBI group, and they were dropped from the analysis. The initial discriminant function was performed on the remaining 64 cases (24 controls, 20 mild TBI and 20 moderate/severe TBI). Unfortunately, a significant Box's M test ($\underline{p} < .001$) indicated heterogeneous variance-covariance matrices. Tabachnick and Fidell (2001) describe the Box's M test as "a notoriously sensitive test" (p. 330) and indicate that Box's M test can be disregarded if sample sizes are equal because the significance test is then assumed to be robust; however, if sample sizes are unequal, robustness is not guaranteed. With this in mind, four control cases were randomly selected and dropped from the analysis and the final discriminant function was performed on 60 cases (20 controls, 20 mild TBI and 20 moderate/severe TBI).

One discriminant function resulted, with a X^2 (2) = 9.00, p = .01. The single discriminant function accounted for 100% of the between group variability, and table 7 presents the standardized discriminant function coefficients and structure coefficients. Stevens (1996) recommends using the standardized discriminant function coefficients to determine the contribution (e.g., importance) of each variable to the discriminant function. The structure coefficients are used to assign a meaningful label to the discriminant function.

Table 7
Standardized Discriminant Function and Structure Coefficients

Variable	Standardized discriminant function coefficients	Structure coefficients
WCST Prop. Persev. Errors	1.00	1.0
WCST Categories Completed		-.64
DEX Self		.20
Digit Span Backward		-.17
BADS Key Search		-.06
BADS Rule Shift Cards		.03

Examination of the standardized discriminant function coefficients indicated that the computerized WCST Proportion of Perseverative errors score was the most important predictor variable in differentiating groups. As seen in figure 4, the centroids for the control and mild TBI groups were located on the negative end of the discriminant dimension, while the centroid of the moderate/severe TBI group was located on the positive end of the dimension. The positive structure coefficient for WCST Proportion of Perseverative errors indicates that this variable is more descriptive of groups on the positive end of the dimension. Based on past neuropsychological and cognitive neuroscience research that has validated the use of the WCST in various clinical populations (Heaton et al., 1993; Kimberg, D'Esposito, & Farah, 1997; Demakis, 2003), this dimension appears to represent a psychological factor associated with perseverative response tendency.

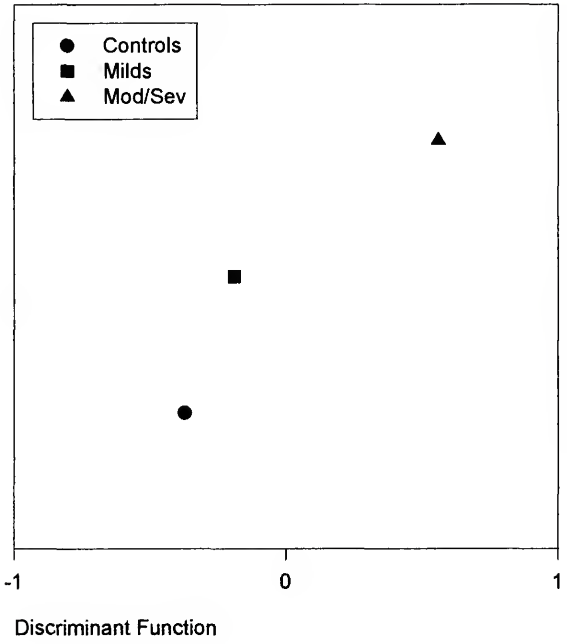

Figure 4. Group centroids for discriminant function.

DISCUSSION

Between Group Performance Differences

One of the primary purposes of the present study was to determine if controls, mild, and moderate/severe TBI participants performed differently on a battery of executive functioning tests. We hypothesized that group mean performance scores, on *individual* tests designed to measure executive dysfunction, would differ as a function of group membership, and specifically predicted that controls would have the best performance followed by mild TBI and then moderate/severe TBI participants.

Results from the study generally supported our predictions. On 18/27 dependent variables controls performed best followed by mild TBI and then moderate/severe TBI participants. No statistically significant differences between controls and mild TBI participants were found on any dependent variable in this study; however, significant differences between controls and moderate/severe TBI participants were found on 17/27 dependent variables. Moderate/severe TBI participants performed significantly poorer than mild TBI participants on 11/27 dependent variables. There were significant differences between groups on 88% of cognitive psychological tests, 69% of neuropsychological tests and 17% of tests of everyday executive dysfunction.

An interesting finding in this study was that both mild and moderate/severe TBI patients showed greater interference on the card Stroop task than controls (see Table 3). This finding is in opposition with previous findings in the literature (Rojas & Bennett, 1995; Stuss et al., 1985). Most of these studies have found that TBI participants show greater interference on the card Stroop based on group-wise comparisons on the color-word naming condition, rather than computing an "interference" score to control for the effects of TBI-related generalized slowing (Perlstein et al., 1998). As an alternate means of comparison, the proportion of errors between groups on this task showed the expected interference effect, but the difference did not reach statistical significance (Seignourel, Robins, Larson, Demery, Cole, & Perlstein, 2004).

No significant differences between controls and mild TBI participants on any test may have occurred because the effect may have been too small to detect with the study sample size. Another reason for the lack of significant findings between controls and mild TBI participants may have been due to the significant amount of time post-injury that had elapsed (average=20 months) in our mild TBI group. A relatively small number of individuals remain symptomatic following mild TBI (Alexander, 1995; Binder, Rohling, & Larrabee, 1997). In fact, some authors have reported that most individuals recover cognitive functioning by 3-months post-injury (Alexander, 1995; Dikmen & Levin, 1993). Statistically significant differences between controls and mild TBI participants may have been found if we had sampled patients who were less than 1-month post-injury. Future studies should incorporate the use of a single battery of executive functioning tests at different time points in the recovery period following TBI to determine if and when differences in diagnostic accuracy occur.

Operating Characteristics

Controls and All TBIs

When considering which operating characteristic is most important in terms of diagnostic accuracy, we selected positive predictive power because it takes into account the number of true positives among *all* test positives (true positives and false positives), whereas test sensitivity measures true positives among the patient population only (true positives; Retzlaff & Gibertini, 2000). As a consultant, the neuropsychologist does not always know if the disorder (TBI) is present in the individual they are testing (N of one case). In fact, in some cases (e.g., litigating mild TBI), the referring physician may not fully know if the disorder is present. Basing clinical decision making on operating characteristics such as positive predictive power mimics real-life clinical decision making and should be considered when selecting tests, though other issues are also important. Characteristics such as an understanding of the measurement error associated with a test should also be considered. In some diagnostic situations, erroneous diagnostic decision making is more problematic than in others. For example, in cases where early detection of a neurological disease is necessary in order to start early treatment (e.g., cases of mild cognitive impairment, fast-growing tumors), one should select tests based on rates of error and sensitivity. In cases where diagnostic accuracy is less critical (e.g., assessment of neuropsychological sequelae after TBI), the implications of making diagnostic errors are not as grave. Given this, the clinical context in which testing occurs should determine what test features receive paramount attention when selecting neuropsychological tests.

We identified the operating characteristics of executive functioning tests in a sample of controls and traumatic brain injury participants, and we hypothesized that cognitive psychological tests would yield higher PPP when compared to traditional neuropsychological tests or tests of everyday executive dysfunction. Partial support for our hypothesis was obtained, although the numerical differences in PPP between cognitive, traditional neuropsychological, and tests of everyday executive dysfunction were not significantly different.

When controls and all TBI participants were pooled together and performance was analyzed at the 1.0 SD level of impairment, the tests that were best able to predict the presence of a TBI were the computerized WCST (proportion of perseverative errors and categories completed) and the Digit Span backwards test. Results showed that the computerized WCST proportion of perseverative errors variable best predicted the presence of a TBI with a high PPP of .95. Based on these findings, individuals who scored at the cutoff were 9.4 times more likely to have sustained a TBI than individuals who performed below that level. The categories completed variable of the computerized WCST achieved a PPP of .92 (odds ratio = 5.7 times more likely to have sustained a TBI), and the Digit Span backward test was also a good predictor of the presence of TBI (PPP = .92; odds ratio = 6.3).

The tests that were poor predictors of the presence of a TBI were the BADS Modified Six = Elements (MSE) test, computerized Stroop (Color-short incongruent), and the Digit Span forward test. Results showed that the BADS MSE test was the poorest predictor of the presence of a TBI with a PPP of .70 (odds ratio = 1.2), followed by the computerized Stroop – color short incongruent trial variable (PPP = .71; odds ratio = 1.3) and the Digit Span forward test (PPP = .71; odds ratio = 1.3).

Our findings of variable rates of positive predictive power across executive functioning measures are similar to those of other researchers who have studied the operating characteristics of executive functioning tests in other clinical populations (e.g., ADHD children and adults; Grodzinsky & Barkley, 1999; Lovejoy, Ball, Keats, Stutts, Spain, Janda, & Janusz, 1999). Grodzinsky & Barkley (1999) found positive predictive power rates from .65 (WCST – failure to maintain set) to 1.0 (Rey-Osterrieth Complex Figure) on tests they administered to children with (n=64) or without (n=66) ADHD (prevalence rate = .51). However, neither the Stroop, Trail Making Test, WCST, nor Controlled Oral Word Association test reached PPP rates in the .90 range. Lovejoy et al., (1999) reported PPP rates from .86 (Trail Making Test part B) to 1.0 (Stroop, Trail Making Test part A, Wechsler Adult Intelligence Scale Distractibility Index) on tests that were administered to adults with (n=26) or without (n=26) ADHD (prevalence rate = .50). Our clinical population may be similar to the clinical groups used in the aforementioned studies given that brain dysfunction in both TBI and ADHD may involve the frontal lobes and executive systems. These findings also suggest that either tests of executive dysfunction have different operating characteristics, or that the executive dysfunction seen in TBI vary across individuals and to the extent that any particular test measures the specific executive dysfunction that a TBI patient has, it is sensitive. A test's sensitivity and PPP are likely related to the demand characteristics of the test.

Controls and Moderate/Severe TBIs

The tests that were best able to predict the presence of a moderate/severe TBI were the computerized WCST (proportion of perseverative errors), computerized WCST (Categories Completed), and the Digit Span test (Backwards). Among all dependent variables in the study, results showed that the computerized WCST proportion of perseverative errors variable was best able to predict the presence of a moderate/severe TBI (PPP = 93). When an individual obtained a score at the 1.0 SD level of impairment on this variable, they were 13 times more likely to have sustained moderate/severe brain dysfunction than individuals who performed above that level. The computerized WCST categories completed variable was second highest among controls and moderate/severe TBI participants and achieved a PPP of .91 (odds ratio = 9.2 times more likely to have sustained moderate/severe brain dysfunction). The Digit Span backwards variable reached a PPP of .90 and individuals who scored at the cutoff score were 8.3 times more likely to have sustained a moderate/severe TBI than individuals who performed above that level. Overall, the diagnostic accuracy of these tests appeared good.

Tests that were poor predictors of the presence of a moderate/severe TBI were the BADS Modified Six Elements (MSE) test, computerized Stroop (Color-short incongruent), and the Digit Span forward test. Our findings indicated that the BADS MSE test was the poorest predictor of the presence of a moderate/severe TBI with a PPP of .50 (odds ratio = .92), followed by the Computerized Stroop Color-short incongruent trials which had a PPP of .62 and odds ratio of 1.5, and then the Digit Span Forward test with a PPP of .63 (odds ratio = 1.5).

Controls and Mild TBIs

The tests that best predicted the presence of a mild TBI were the computerized WCST (proportion of perseverative errors), Digit Span test (Backwards), and the traditional (card) version of the WCST (proportion of perseverative errors). Results showed that the PPP for the computerized WCST proportion of perseverative errors variable was best able to predict the presence of a mild TBI (.80). When an individual obtained a score at the 1.0 SD level of impairment, they were 4.8 times more likely to have sustained a mild TBI than individuals who performed above that level. The Digit Span Backward test was second highest among controls and mild TBI participants achieving a PPP of .75 (odds ratio = 3.6 times more likely to have sustained a mild TBI). On the traditional (card) version of the WCST, proportion of perseverative errors achieved a PPP of .75 (odds ratio = 2.2 times more likely to have sustained a mild TBI).

The tests that were poor predictors of the presence of a mild TBI were the computerized Stroop (Color-short incongruent), AX-CPT Interference (d' AX Int. Long), and the computerized WCST (Categories Completed). Results showed that the computerized Stroop color-short incongruent trials variable was the poorest predictor of the presence of a mild TBI with a PPP of .44 (odds ratio = .96), followed by the AX-CPT Interference variable d' AX Int. Long which had a PPP of .44 and odds ratio of .96, and then the computerized WCST categories completed with a PPP of .50 (odds ratio = 1.2).

Our findings are consistent with previous research that evaluated the diagnostic accuracy of attention measures after mild TBI (Cicerone & Azulay, 2002). The authors administered a battery of attention measures to individuals with persistent post-concussive syndrome (n=32) and healthy controls (n=32; prevalence rate=.50) and found positive predictive power rates of .40 (Stroop interference) to .72 (Trial Making Test part A) when using a cutoff at the 1.0 SD level of impairment. In our controls (n=24) vs. mild TBI (n=20) comparisons, we found higher positive predictive power on the Digit Span backward (our study/Cicerone & Azulay = .75/.50) and Stroop (.56/.40) tests. We found lower positive predictive power on the PASAT (.55/.65), Trail Making Test part A

(.67/.72), and Digit Span forward test (.46/.66). Both studies found equivalent positive predictive power on the Trail Making Test part B (.67/.67). Coupled together, these studies demonstrate that these tests have moderately high rates of positive predictive power and have value in the diagnostic assessment of mild TBI.

The differences in positive predictive power across computerized versus card versions of the WCST may have occurred for several reasons. First, the card version was always administered before the computer version in this study. This was done to ensure that the concept formation aspect of the WCST (e.g., sort by color, shape, number) remained novel during the card version. The administration of the card before the computer version of the WCST coupled with the instructional cues that are provided before taking the computerized WCST are meant to remove the concept formation aspect of the computerized task. This is suppose to have the effect of placing greater demands on the ability to negotiate the perseverative response tendency. Perseverative errors have consistently been the most sensitive dependent variable on the WCST (Demakis, 2003) and our computerized version of the test places a strong demand on perseverative responding. For example, there are only 128 sorts in the traditional card version of the WCST while there are 288 sorts in the computerized version. This increase in the number of sorts results in a greater number of behaviors (e.g., sorts) and is more likely to reveal a perseverative response tendency in the participant if one is present. The same can be said about the number of categories achieved. In the traditional version, only six categories may be achieved, but fifteen categories can be achieved in the computerized version. This again increases the likelihood of finding an effect in an individual. Second, the introduction of a 5-second time limit for each sort on the computer version may have led to greater perseverative responding and fewer categories achieved for the moderate/severe TBI group on the computer administration compared to the card version of the WCST. Third, fewer participants took the card version (n=37) as compared to the computer version of the test (n=70) which may have resulted in a smaller effect size for the card version.

The computerized WCST proportion of perseverative errors achieved high positive predictive power in cases of mild and moderate/severe TBI, but the variable categories completed achieved high positive predictive power in moderate/severe TBI cases only. The finding of dependent variables with disparate utility in TBI illustrates the importance of considering all data (dependent variables) from tests before deciding if a test is useful in select clinical populations. The findings may suggest that some tests may be administered in a manner that maximizes the acquisition of "relevant" dependent variables and minimizes time spent obtaining meaningless ones. While it is difficult to see how the WCST could be administered in its current form without some index of the number of categories that were completed, tests like Digit Span may be altered to inform the clinician about digits backward only. This cuts administration time in half for this test and allows time and effort for more meaningful evaluative methods. In the future, those who develop neuropsychological tests should consider which dependent variables are most useful and develop tests based on those findings.

The findings that performance was worse in the computerized WCST (where instructional cues are given) are not consistent with the work of other researchers who provided instructional cues on the card version of the WCST and subsequently found improved performance in schizophrenics (Goldman, Axelrod, & Tompkins, 1992). The fact that the computerized version used in our study requires responses within a time deadline may have been the reason for the discrepancy. Slowed rate of information processing speed in our moderate/severe TBI group may have contributed to an inability to consistently make correct sorts.

Discriminating Groups

Our final purpose for conducting the study was to determine if predictor variables from neuropsychological tests were able to reliably discriminate groups (e.g., control, mild, or moderate/severe). We predicted that a weighted linear combination of predictor variables that could discriminate groups would include more cognitive psychological tests than traditional neuropsychological tests or tests of everyday executive dysfunction.

The findings showed that only the computerized WCST proportion of perseverative errors variable was useful in discriminating groups. A perseverative response tendency is the repetition of a behavior even when it is no longer appropriate (Kimberg, D'Esposito, & Farah, 1997b). More specifically, a stuck-in-set perseveration is the inappropriate maintenance of a current category or framework (Sandson & Albert, 1984). Stuck-in-set perseverations may be considered a defect in response inhibition (Roberts & Pennington, 1996) and are indicative of executive dysfunction. However, Kimberg, D'Esposito, & Farah (1997b) suggest that a defect in working memory may account for perseveration. Cohen & Servan-Schreiber's (1992) asserted that working memory deficits are impairments in the ability to construct and maintain internal representations of information (context maintenance) that are to be held in mind in such a form that they can be used to mediate appropriate behavioral responses. Based on this idea, Kimberg et al. (1997) proposed a spread of activation model of working memory that attributed perseverative responding not to inhibitory dyscontrol, but to an inability to utilize context (criterion change) to actively select a new response that fits the new criterion. In our study, moderate/severe TBI patients performed very poorly on measures of working memory (N-Back High), suggestive that they may have made more perseverative response due to a defect in context maintenance. In addition, an analysis of the structure coefficients in the discriminant function analysis showed a negative (small) correlation between the discriminant function and performance on the Digit Span backward test – a measure of working memory. Further indicating that faulty working memory may play an important part in the behavior of perseveration. Future studies should attempt to further distinguish the role of working memory in perseveration and directly address the concept of perseveration in light of these findings.

One of the greatest challenges facing executive functioning test developers is the task- impurity problem. This refers to the notion that executive functioning tests also make demands on a variety of other cognitive skills or functions that are supported by brain structures that are quite independent of frontal cortex (Rabbitt, 1997). The development of cognitive psychological tasks, such as those used in the present study, is an attempt to create experimental paradigms that elucidate the nature of defective functioning of the component processes of executive functioning (e.g., inhibitory control, working memory, etc.) after TBI.

While cognitive psychological tests may provide “purer” information about executive functioning/control, it is unlikely that dependent variables with greater conceptual “purity” provide greater sensitivity or predictive power than omnibus tests that make demands on multiple functional systems. A test that has multiple demand characteristics requires the integrity of an entire functional system, and if any element of that system is impaired, it is likely to manifest as impaired system (test) performance. The dilemma that clinicians face is that omnibus tests appear to be more sensitive to the presence of brain dysfunction and are subsequently better at detecting the presence of a disorder when it is present; however, omnibus tests do little in terms of explaining the unique variance that exists between executive functioning/control measures. Purer tests more clearly inform the clinician about the integrity of component processes of executive behavior, but they unfortunately are not likely to provide the sensitivity and predictive power of omnibus tests. This result was observed in the present study - the omnibus test WCST yielded the greatest PPP while an arguably pure test of working memory, such as the N-Back, had high PPP but not as high as the WCST. These findings support the idea that clinicians should select tests based on the nature of the referral question (e.g., Is there a disease present? vs. Does this person have executive dysfunction?).

According to Sbordone (1996), ecological validity refers to “the functional and predictive relationship between the patient’s performance on a set of neuropsychological tests and the patient’s behavior in a variety of real-world settings (e.g., home, work, school, community)” (p. 16). While neuropsychological tests have been generally useful in detecting and/or quantifying brain dysfunction, the tests continue to lack relevance in predicting real-world behavior (Wilson, Evans, Alderman, Burgess, & Emslie, 1996). We included a broad range of executive functioning/control tests that we considered differentially ecologically valid. For example, we included tests that were thought to have low ecological validity but high sensitivity (e.g., cognitive psychological tests). We selected tests touted as measures of high ecological validity (Wilson et al., 1996) but with predicted low sensitivity (e.g., Tests of everyday executive dysfunction). We felt that traditional neuropsychological tests had generally low ecological validity, albeit higher than cognitive psychological tests, and adequate sensitivity, albeit lower than cognitive psychological tests. Results showed that while tests of everyday executive dysfunction are touted as having good ecological validity, they lacked sensitivity and predictive power in the present study to warrant use in outpatient clinical settings with individuals with chronic TBI. These findings notwithstanding, tests of everyday executive dysfunction may yield higher rates of sensitivity and predictive power in individuals with acute TBI. Test developers should continue attempting to expand the use of neuropsychological tests in predicting real-world behavior.

While the task impurity problem and issues of ecological validity are important obstacles in the assessment of executive functioning/control, probably the most controversial yet important issue is the problem of the definition and use of the term executive functioning. Although Lezak (1995) defined executive functioning as “the capacity that enables a person to engage successfully in independent, purposive, self-serving behavior” (p. 42), this definition does little in terms of clearly elucidating the component processes subsumed under executive functioning/control. There is little question that the term ‘executive functioning’ facilitates discussions about a nondescript set of abilities that sit atop the cognitive hierarchy. However, the term does little in terms in promoting a more precise understanding of the component processes that comprise executive behavior. Executive functioning/control is the final common pathway for a multitude of subordinate behaviors that must be intact in order for the organism to perform executive behavior. Neuropsychologists must be able to understand where in the cognitive hierarchy impaired functioning is occurring (e.g., perceptual systems, updating, active maintenance, etc.) in order to best understand the nature of executive dysfunction.

Limitations of this study should be considered. The sample size used in this study was small. In light of past research that indicates a small but consistent effect in performance on neuropsychological tests between controls and mild TBI participants (Binder et al., 1997), future studies should include larger samples to determine if significant differences between controls and mild TBI participants exist on the tests that were unique to this study.

Although the retrospective method of collecting information about brain injury severity has been validated in past studies (King et al., 1997; McMillian, Jongen & Greenwood, 1996), having acute medical records on all TBI participants is an advantage when classifying participants in research studies. A limitation of the current study is that only 7 of 42 participants who were treated in the ER immediately following their injury brought medical records at the time of study participation.

The inclusion of acute injury data such as Glasgow Coma Scale score, duration of loss of consciousness or post-traumatic amnesia, or positive cranial nerve III sign (dilated pupil), would be very important in improving diagnostic accuracy and in discriminating between groups.

Appendix
Structured Clinical Interview Form

Date:______________

Subj. Name:___________________________________ Subj. #:_________ Control or

TBI Gender: M or F* Race*: ___________D.O.B.:_________(Age_____)

Handedness: L R Mixed

Date of initial contact

Date of 2nd contact

Date of 3rd contact:

Date of 4th contact:

Does the patient meet inclusion criteria for behavioral study?	Yes or No
Has the patient signed the informed consent?	Yes or No
Date signed informed consent	_________
Has the patient been scheduled for behavioral study?	Yes or No
Date patient to participate in behavioral study	_________
Date patient participated in the behavioral study	_________
Does the patient meet inclusion criteria for the fMRI study?	Yes or No
Has the patient signed the informed consent?	Yes or No
Date signed informed consent	_________
Has the patient been scheduled for fMRI study?	Yes or No
Date patient to participate in fMRI study	_________
Date patient participated in fMRI study	_________
Has the patient been sent his/her payment for participation?	Yes or No
May the patient be contacted for future research studies?	Yes or No

Date:______________

Subj. Name:__________________________________ Subj. #:________ Control or

TBI Gender: M or F* Race*: __________D.O.B.:_________(Age____)

Handedness: L R Mixed

Address:____

_____ Home Ph.# (______)______________ Work

Ph.#(______)_____________

Years of education (YOE) Pt*:________Y.O.E. Mother:_______Y.O.E. Father:_______

Pt's Occupation (Be specific)*:____ Mother's

Occupation (Be specific):____

Father's Occupation (Be specific):____

Pt's level of functioning *before* TBI**:____________

Pt's level of functioning *after* TBI**:_____________

Pt's Marital Status: S M D W Residence*: < or > 2500 Legal status**:_______

Did the pt. go to the ER as a result of accident? Yes or No

Was Pt. admitted to the hospital from the ER? Yes or No

If yes, duration of hospitalization (Days):______

Mechanism of injury**:_________ Type of injury**:_______

Time since injury (Months):_________

LOC associated with accident? Yes or No

If Yes, est. duration of LOC (in minutes):______

PTA associated with accident? Yes or No

If Yes, est. duration of PTA (in minutes):______

Estimated duration of retrograde amnesia (in minutes):________

Estimated duration of anterograde amnesia (in minutes):_______

Prior Medical History (Before TBI)? Yes or No

____

____

Prior History of Neurological insult (e.g. TBI, CVA)? Yes or No

____

____

Prior History of serious Psychiatric/Psychological Disorder? Yes or No

If yes, Dx:____________________When:________________________

How treated:________________________ How long:______________

If female, are you currently pregnant? Yes or No

If No, is there a possibility that you are? Yes or No

Current medications:______________________________________

____

Medication or recreational drugs taken within the last 24 hours:______________

____

Overall GPA in High School:________ In College:________

Problem Areas?______________________ Prior Hx. of LD?____________

Hx. of Special Education Classes?______________________________

Hx. of ADD or ADHD:______________________________________

Hx. of drug or alcohol abuse:__________________________________

Average number of alcoholic drinks per week:________________________

Have you participated in research studies before? Yes or No

If yes, specify____

When was the last time you had neuropsychological testing?________________

Do you have any metal clips or plates in your body or past bridgework? Yes or No

What are the best days and times for you to participate in the research study?

____

Will you be willing to sign a release for medical records if necessary? Yes or No

If yes, date signed________________

Level of functioning before TBI

0=Pt. employed or student
1=Pt. ½ time employed or ½ time student
2=Pt. not employed or attending school

Level of functioning after TBI

0=Pt. returned to premorbid activities with no modification
1=Pt. returned to premorbid activities with moderate modifications
2=Pt. unable to return to premorbid activities

Litigation status

0=not in litigation, no future plans of litigation
1=not in litigation, future plans of litigation
2=in litigation
3=past litigation related to accident

Mechanism of injury

0=Motor vehicle accident
1=MVA vs. pedestrian
2=Fall
3=Assault
4=Sport/recreation injury
5=Other, specify

Type of injury

0=Acceleration
1=Deceleration
2=Pure acceleration with blunt head trauma
3=Pure deceleration with blunt head trauma
4=Acceleration and Deceleration without blunt head trauma
5=Acceleration and Deceleration with blunt head trauma

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BIOGRAPHICAL SKETCH

Jason Andrew Demery was born to Linda and Gerald Demery of Granite City, Illinois, on February 3, 1969. Jason graduated from Granite City Senior High School in 1987 where his focus of study was in vocational machine shop and welding. He joined the United States Marine Corps in 1987 and served as a Sergeant in the signals intelligence field until he was honorably discharged in 1995. That same year, he graduated with honors from the University of West Florida with a Bachelor of Arts degree in psychology. Jason completed a Master of Arts degree in clinical psychology in December 1996 from Southern Illinois University in Edwardsville, Illinois.

After working from 1996-1998 at the Brain Injury Day Treatment Program at Barnes-Jewish Hospital/Washington University School of Medicine in St. Louis, Missouri, he began graduate school at the University of Florida in the Department of Clinical and Health Psychology. Upon matriculating to the University of Florida, he was awarded the Dean of the College of Health Professions Research Scholarship. While at the University of Florida, Jason conducted research in the Departments of Clinical and Health Psychology and Neuroscience, and was instrumental in developing a clinic focused on the assessment and treatment of symptoms associated with concussion.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Public Health and Health Professions and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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